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45. 249.

THE

GLOBES,

CELESTIAL AND TERRESTRIAL.

BY

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"Non est in potestate nostra cœlos sursum adire, circulos et gradus eorum visu cernere, eosque revolvere undecunque et quando placuerit. Quæ preterita in illis sunt, haud homo potest intueri; nec hominis ætas sufficeret expectare quæ futura sunt; et quæ presentia sunt dum vivit homo, cuncta nemo videre potest. Quas ob res bonum et commodum est artificialem sphæram habere; quæ manibus ad libitum volvi et secundum convenientem situm et partem conspici possit."—COMMENT. IN SACROBOSCUM.

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PREFACE.

This work is specially intended to accompany Malby's Globes, published under the superintendence of the Society for the Diffusion of Useful Knowledge: but it may be studied with any others. In its astronomy, it describes only the appearances of the heavens, without any reference to their producing causes: it is therefore independent of all systems, and might even be approved* by believers in the stability of the earth, if there be any left. The reasons for the adoption of this plan are fully stated in the introductory chapter: they are, first, that the celestial Globe imitates only actual appearances, and therefore only requires the description of actual appearances; secondly, that persons in general learn the true system and neglect the apparent one, to an extent which makes it desirable that there should be works on the use of the globes which describe the latter without allusion to the former.

The time was when the only elementary work on astronomy was the description of the celestial sphere. The quotation in my title-page is a passage of commentary inserted near the commencement of one of the earliest printed editions of the celebrated work of Sacrobosco, the astronomical Euclid of the middle ages. As the Copernican theory gained ground, the globe, which represented the *real belief* of the falling sect, was no longer judged essential to instruction in the science. The distinction between *astronomy* and the *use of the globes* (for every advertisement of a school tells us that they *are* two distinct things) began to appear with the seventeenth century. The earliest English work of note which makes the distinction and treats on the globes is that of Robert Hues. During the last century the average character of works on this subject has been lowered: the respectable names of Keith, Ferguson,* Walker, and others, have been associated with those of authors who seem to have thought that the pretext of writing for the especial instruction of young ladies was more than a sufficient excuse for any amount of nonsense.†

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* Except only that the motion of the earth is alluded to in p. 14, as causing aberration, and in p. 118 there is one paragraph alluding to the real planetary motions.

The globes give some idea not only of the phenomena of the heavens, but also of the processes by which the astronomer makes them useful in the determination of latitude, longitude, and time. Those who cannot see the heavens for themselves at all times of the day and night, will find these instruments a useful substitute: no recommendation of them is necessary to those who take pleasure in watching the motion of the stars. As to their use in education, the only question is, should young persons learn any notions of geography and astronomy? If the answer be in the negative, there is nothing to be said for the globes. But if it should be in the affirmative, there is nothing to be said against them. For it is certain that no map of the earth can be well understood except by one who is familiar with the terrestrial globe: and that there are not any such opportunities in this climate as would, even were it otherwise desirable, enable the instructor to dispense with the celestial globe.

---

* The excellent little treatise by Ferguson, one of the clearest of self-taught writers, was last reprinted, I believe, by Messrs. Cary, in 1828, as a companion to their globes.

† To show that this is not too severe, I make a few extracts from the questions for examination appended to the *fourteenth edition* of a work written expressly for young ladies; which questions are to be answered, and can be answered, from the work itself. Among the questions on *Sagittarius* are the following: "To what sin were the Athenians addicted? What reflection does Dr. Doddridge make on the occasion?" Apropos of the constellation of *Ursa Major* is this question, "Who drove stags in his phaëton, instead of horses?" and the answer is, "Lord Orford, who died in 1791." The concatenation is that bears can be tamed, and that Prince Radzivil drove them in his carriage at Warsaw. On *Musca* the questions are: "What are the distinguishing characteristics of flies? In what manner, demonstrating his propensity to cruelty, did Domitian treat them? Hence what sarcasm was passed upon him? How has Sterne represented the humanity of a feigned character to a fly? How did contrary behaviour in a female (according to Darwin) break off an expected matrimonial connexion?"

For those who like to mix miscellaneous astronomical information with lessons on the globes, there are the 'Lessons on the Globes,' by T. H. Howe, which abound in interesting extracts from good writers, and which claim no kindred with the work just quoted, except in some mnemonical verses at the end, which the author would do well to strike out of his next edition.

The boundaries of the constellations on Malby's globes are slightly different from those usually laid down; the reasons for the alteration are described in Chapter V. of this work. The broad lines which mark the adopted boundary were laid down for Malby and Son, at my request, by my lamented friend Francis Baily. It should however be stated that they do not go the full length of alteration which he would have approved, if left entirely to his own judgment: he deferred to my opinion that, as it was not intended the alterations should have the sanction of his name, no change should be made except in correction of obvious incongruity, and then only when it could be done without great inconvenience.

In the statement (page 52) of the stars asserted by Mr. Argelander to be visible to the naked eye, but not contained in any catalogue, I find I have represented him as giving forty such stars, whereas in fact he has but twenty-seven. The thirteen which are to be struck out of my list are, naming them by their constellations and degrees of right ascension, as follows: —Cetus 28, Gemini 89, Canis Major 99, Monoceros 121, Draco 250, Hercules 258, Ophiuchus 260, Ophiuchus 264, Hercules 273, Sagittarius 281, Sagittarius 284, Cygnus 321, Cepheus 331.

In page 58, the obscure constellation introduced by Lemonnier, under the name of Solitarius, is translated the *Hermit.* I have not now the means of referring to Lemonnier, but I find that Lalande and Bode both state this Hermit to be a bird (l'oiseau des Indes, L'Ermite, Einsiedler); it is the *Dodo.*

In the last chapter are described a globe for exhibiting the precession of the equinoxes, a new form of the movable planisphere, and *Globe-atlases*, each consisting of twenty-one sheets, which can also be disposed on thirty-six inch globes: all published by Malby and Son. This last named celestial atlas or globe (which was originally intended for either) contains the nebulæ, which it has not hitherto been usual to place on globes. There is no doubt that the introduction of these bodies would confuse a small design; but a diameter of 36 inches gives ample room for them. A globe of 36 inches diameter has more than 28 square feet on its surface, and the daily motion of the moon upon it is more than four inches.

A. De Morgan.

University College, London,
May 16, 1845.

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⁂ Explanations of a few old terms which are seldom or never used by astronomers, but have been allowed to remain in works in the use of the globes:—

Almacanters, a term from the Arabic, used to signify parallels of altitude, or small circles parallel to the horizon.

Zones. A zone is the portion of the sphere cut off by a circle, or contained between two parallel circles. The parts of the earth within the tropics bear the name of the *torrid zone:* from the boundaries of the torrid zone to the arctic and antarctic circle we have the *temperate zones:* and the parts of the globe cut off by the arctic and antarctic circles are the *frigid zones.* These terms have been little used even by geographers, since it has been well ascertained that what we now call climate is not everywhere the same in the same latitude.

Climates. The old use of this term is as follows:—The day at the equator being always twelve hours, and the longest day at the arctic and antarctic circles being twenty-four hours, draw the successive parallels to the equator at which the longest days are 12½, 13, 13½, &c. hours, on both sides. The zones intercepted between these parallels bore the name of climates. But this is only one mode of forming climates, several others having been adopted by different writers.

Right, oblique, and parallel spheres; oblique ascension. When the poles are in the horizon, the sphere was called *right;* when elevated above the horizon, but not so much as 90°, *oblique;* when in the zenith, *parallel.* The term *ascension* was applied to the degree of the equator which rises with any heavenly body: thus the ascension of the sun is 17° when the point of the equator which is 17° more advanced than the vernal equinox rises with it. In a right sphere the ascension was called right ascension, a term which has lasted: what we now call the right ascension of a star is, as much as ever, dependent on the point of the celestial equator which rises with the star at the earth's equator. In the oblique sphere the ascension was called *oblique ascension,* a term entirely out of use.

Antœci, Periœci, and *Antichthones.* Those who have the same longitude, and equal latitudes north and south, are *antœci:* those who have the same latitude, but are on opposite meridians, are *periœci.* Those who are in all respects opposite, are *antichthones,* or antipodes; and this last is the only term of the four now used. But it is more consistent with the most ancient usage to call all who are on the same parallel of latitude periœci, and all who are on opposite parallels antœci.

Amphiscii, Heteroscii, and *Periscii.* Those who live in the torrid zone were called *Amphiscii,* as having their noonday shadows sometimes cast north, sometimes south; those in the two temperate zones were called *Heteroscii,* the noonday shadows of each being always thrown one way, but those of the two always in different ways; those in the frigid zones were called *Periscii,* from their visible shadows making complete revolutions.

LIST OF THE PROBLEMS solved in this work, with some examples for practice on those which are of most use.

⁂ *In order to avoid the casual errors of a particular globe, the answers to the following questions, whenever numerical, have been determined either by calculation or tables.*

Page 6. To turn angular measure into time, and time into angular measure.
Example. Show that $11^h\ 32^m\ 45^s$ is 173° 11′ 15″, and that 43° 29′ 6″ is $2^h\ 53^m\ 56^s\frac{2}{5}$.
—— 14. To compound rectilinear motions in the same or opposite directions.
—— 15. To compound rectilinear motions in different directions.
—— 17. To compound curvilinear motions.
—— 21. To find the interval of conjunction of two revolving bodies.
Ex. 1. If the sun revolve in 365 days and the moon in 27 days, what will be the interval of two conjunctions? *Ans.* 29 days, 4 hours nearly.
Ex. 2. If in the last we substitute 365¼ and 27⅓, which are nearer the truth, what is the interval of two conjunctions? *Ans.* 29 days, 13 hours nearly.
Ex. 3. Two bodies revolve in opposite directions, in 3 hours and 3½ hours; what is the interval between two conjunctions? *Ans.* 1 hour, 37 minutes nearly.
—— 28. To find the latitude and longitude of a point on the globe.
Ex. What are the latitudes and longitudes of Quebec, Maranhao, Pekin, Oporto, and Moscow? *Ans.* 46° 50′ N., 71° 16′ W.; 2° 31′ S., 44° 19′ W.; 39° 59′ N., 116° 28′ E.; 41° 8′ N., 8° 37′ W.; 55° 42′ N., 37° 35′ E.
—— 28. To find what place is in a known latitude and longitude.
Ex. What places are in 47° 14′ N., 5° 5′ E.; 54° 39′ S., 158° 41′ E.; 52° 29′ N., 1° 54′ W.; 43° 10′ N., 79° 5′ W.? *Ans.* Dijon, Macquarrie Island, Birmingham, Niagara.
—— 29. To find places having nearly the same longitude as a given place, or nearly the same latitude.
—— 29. To find the distance between two places on the earth.
Ex. What are the distances from the place 4° 6′ N., 174° 31′ E. to the several places 22° 2′ N., 68° 52′ E.; 28° 24′ N., 113° 51′ E.; 24° 31′ N., 149° 56′ E.; 10° 19′ S., 160° 50′ W.; 16° 40′ S., 127° 24′ W.; 26° 4′ S., 115° 8′ W.? *Ans.* 102° 50′, 62° 20′, 25° 50′, 28° 30′, 61°, 74° 20′.
—— 32. To turn degrees, &c. on the earth into miles.
Ex. How many miles are there in 22° 29′ and in 6° 19′? *Ans.* 1524 and 417.
—— 32. To make any point of the globe highest, and to elevate the pole for the latitude of any place.
—— 32. To divide the earth into two hemispheres having a given place and its antipodes for the poles.

Page 33. To find all the places which are at a given distance from a given place.

—— 34. Given either the longitude or latitude of a place and its distance from another place, to find it.

—— 35. How to reckon longitudes from other places besides Greenwich.

—— 35. To describe the points of the compass.

What angle does W.N.W.¼N. make with the north and south directions? *Ans.* 64° 41′ 15″ and 115° 18′ 45″.

—— 36. To find the circular bearings of places from one another.

—— 37. To use the magnetic variation as marked on the globe.

—— 39. To find the degree of longitude on any parallel in miles.

Ex. 1. How many miles are there in one degree of longitude on the parallel which has 38° of latitude? *Ans.* 54⅓ miles.

Ex. 2. In what latitude is a degree of longitude 24 miles in length? *Ans.* 69° 40′.

—— 46. To describe the effects of the diurnal rotation at different parts of the earth.

—— 60. To elevate the axis of the celestial globe for any place.

—— 60. To find the position of the constellations at a given place, when a given star is rising, culminating, or setting.

Ex. What is the position of the heavens at Greenwich, when α Lyræ is on the meridian? *Ans.* The pole of the ecliptic has passed the meridian by about half an hour; and the stars β and γ Draconis by a little more. There is no very bright star, except α Lyræ, on or close to the meridian; α Cygni will be there in a couple of hours, and α Aquilæ in an hour. Spica Virginis set a few minutes ago, and Antares will set in an hour.

—— 61. To find what places have any one star on the meridian at once, what places have the same star vertical during the day, and at what places a star is rising or setting at one time.

⁂ This is not completely finished here; see p. 99.

—— 61. To distribute the heavens over the earth; or to find the constellations which are vertical, &c. over any place, when the position of the heavens is known at any other place.

Ex. What stars are on or near the meridian at Madras and at Quebec when Aldebaran is on the meridian at Greenwich? *Ans.* Regulus is nearly vertical at Madras, and portions of Ursa Major, Leo, Sextans, Hydra, and Argo, are on the meridian. At Quebec, λ Andromedæ is nearly vertical, and portions of Cepheus, Cassiopea, Andromeda, Pegasus, and Aquarius are on the meridian.

—— 63. To find the right ascension and declination of a given star, and the star, if any, of a given right ascension and declination.

Ex. 1. What are the right ascensions and declinations of α Arietis, δ Orionis, β Ursæ Minoris, and α Piscis Australis? *Ans.* $1^h\ 58^m$ and 22° 40′ N.; $5^h\ 24^m$ and 25′ S.; $14^h\ 51^m$ and 74° 50′ N.; $22^h\ 49^m$ and 30° 30′ S.

Ex. 2. What remarkable stars are found very close to $4^h\ 27^m$ and

16° 10′ N.; 6^h 20^m and 52° 40′ S.; 6^h 38^m and 16° 30′ S.; 10^h and 12° 45′ N.; 16^h 19^m and 26° 5′ S.? The answers are not given, but only the information that very brilliant stars are close to these spots.

Page 64. To find the distance of two stars.

—— 65. To find the sidereal time at which a star is on the meridian.

—— 65. To find the position of the heavens by the hour-angle of a star.

Ex. Name some stars which have recently risen when the hour-angle of Arcturus is 2^h 35^m east, at Greenwich. *Ans.* ε and β Cygni, β and ζ Ophiuchi, and γ Libræ.

—— 67. To find a correction, if necessary, for the mode of clamping the flexible arc.

—— 67. Given the altitude of a known star, at a given place, to find the sidereal time.

Ex. At Rome (lat. 41° 54′ N.) the star α Lyræ has 50° of altitude on the east side of the meridian: what is the star's hour-angle, and what is the time of the sidereal day? *Ans.* 53° and 14^h 59^m.

—— 70. To connect the time of either kind of day with the hour-angle of its regulating body.

—— 73. To convert an interval of mean solar time roughly into sidereal time, or of sidereal into mean solar.

—— 74. To find the celestial longitude and latitude of a star by the flexible arc.

—— 75. To do the same by the zodiac. (This second method is the only one which can now be useful, and it is too obvious to require examples.)

—— 77. To find the sun's longitude on a given day.

Ex. At noon, April 19, 1842, the sun's longitude is 29°; July 16, 1843, 113° 14′; January 21, 1844, 300° 37′; September 4, 1844, 162°; March 31, 1845, 10° 38′.

—— 79. To find the equation of time.

—— 83. To set the celestial globe so as to represent the heavens at any true solar hour of any day.

Ex. What is the state of the heavens at a quarter after eight by the sun in the evening of the 9th of August, at Greenwich? *Ans.* α Ophiuchi and β Draconis are very nearly on the meridian.

—— 84. To substitute the equator for the brazen parallel.

—— 85. To represent the heavens at any mean solar hour of any day.

—— 85. To find the *true solar* time of sunrise.

Ex. According to the Almanac, sunrise and sunset take place in 1845, at Greenwich, on the following days, as follows:—January 1, 8^h 9^m and 4^h 0^m; March 18, 6^h 10^m and 6^h 8^m; July 7, 3^h 53^m and 8^h 15^m; September 21, 5^h 46^m and 5^h 59^m: all *mean* or *clock time.* Hence find the times *by the sun* and compare the results with the globe.

—— 86. To try the horizon of a globe.

—— 92. To find when the moon is on the meridian.

Page 98. To find on what days the sun has a given declination.
———. To find the places at which the sun is vertical on a given day.
—— 99. To find when the sun is vertical at any given place.
———. To find at what place the sun is vertical at a given day and hour.
Ex. At what place is the sun vertical, or nearly so, at 9 in the morning at Greenwich, on the 23rd of April, and when is it again vertical again at the same place? *Ans.* At Aden, where it is vertical again on the 19th of August.
———. To find where the sun is rising, on the meridian, and setting, at a given day and hour, by the equator, with using the brazen parallel.
—— 99, 100. To find the sun's altitude at a given place, day, and hour, by the terrestrial globe alone (verify the result by the celestial globe).
—— 100. To find at what places twilight is reputed to be beginning or ending at any given day and hour.
—— 100. To find when the sun is rising, &c. at any given day or hour, by the brazen parallel.
—— 101. To find the time of sunrise and sunset by the terrestrial globe.
—— 101. To find the *circumpolar* portion of the heavens at a given place.
—— 102. To find how long it is perpetually light or perpetually dark (so far as sunlight is concerned) at any place within the arctic regions.
—— 103. To find in what arctic latitude it is perpetually light or perpetually dark for any given number of days.
—— 103. To find the longest or shortest day at any place not within the arctic regions.
—— 103. To find the latitude in which the longest day has a given length.
—— 104. A sort of attempt at finding the time of day by a globe when the sun shines.
—— 104. To place the globe so that the sun shall shine on it in the same manner as on the earth.

A TREATISE

ON THE

USE OF THE GLOBES.

Introduction—Object of the Work—Reasons why it should be confined to apparent Astronomy.

THE earth on which we live is a globe or sphere, or rather it differs so little from such a form, that it is useless for any ordinary purpose to suppose it otherwise. The other bodies of the universe are also spheres, or nearly spheres, placed at such distances from us that, except only the sun and moon, they appear as mere spots of light. We divide the visible universe into earth and heavens, just as an insect who is bred in a tree would, if it could, speak of the things within its knowledge as consisting of its native branch and all the rest of the forest. Both classifications would be just, for their different purposes, and the comparison of them may suggest the possibility of all that we can see, even with the most powerful telescope, being only such an item of the whole creation, as our earth is of the visible part of it, or the insect's branch of the whole forest.

The division into earth and heavens is true and useful, as far as we are concerned. It gives rise to the configuration of all that we know on two globes, one representing the earth we live on, the other the expanse in which lie all the bodies that we perceive only by sight. The different explanations which have been given of the connexion of the heavenly bodies with each other, forming what are called *systems of astronomy*, are the consequences of long trains of reasoning upon what has been observed on earth and in the heavens, upon changes of apparent place which may be imitated on the globes which this book is intended to describe. With these astronomical systems we have nothing to do: as far as power of using and understanding the globes is concerned, it matters nothing whether their owner imagines the sun to move round the earth or the earth round the sun. The globe enables us to imitate the *appearances* of the heavens; two persons, one of whom explains those appearances rightly, and the other wrongly, both go to the globe for the same purpose, use it in the same manner, draw the same conclusion from it, and speak of that conclusion in the same words. It is then totally unnecessary, in teaching the use of the globes, to enter upon the reasons why the appearances are what they are.

But may it not be desirable to mix up with instruction on the use of the globes the interesting description of what is known about the order and connexion of the heavenly bodies? In answer to this question, I observe that there are three distinct steps in sufficient astronomical attainment: the first is, to get an accurate notion of what appears in the heavens, to know well the apparent situations and changes of the heavenly bodies; the second is, to make that knowledge useful in the actual prediction, by means of a globe, of the state of the heavens at any particular time; and the third is, to apply thought and calculation to the deduction of the real motions from the apparent ones. These steps ought to come in order: but it too often happens that a book on the use of the globes is a mixture of the second and third, to the neglect of the first. If this work could be made extensive enough to treat of all three, it would certainly be practicable to take them in separate chapters or sections: but even in such a case, it might well be a question whether it would not be better to leave the third head entirely to one or another of the excellent works on astronomy which are within the reach of the student, and of which it is almost the only serious defect that they do not touch on the first and second heads in sufficient detail. For this the excuse would be, that writers on astronomy do not profess to teach what is better done in books on the use of the globes: and just as well may it be answered, that a writer on the use of the globes need not enter upon what can be more effectively obtained from a professed treatise on astronomy.

There is another and a still stronger reason why a book on the use of the globes should contain nothing but *apparent* astronomy. The time was, when every educated person was tolerably well acquainted with the appearances of the heavens, and came to the discussion upon Ptolemaic and Copernican explanation with a clear idea of what it was about. It is not so now: few persons look at the heavens, while most learn a certain astronomy from books. The books teach the true or real motions of the heavenly bodies, those in particular of the solar system, so well, that if their reader could take up his residence in the sun, he would find himself quite at home, and would have daily illustrations of the Copernican theory passing before his eyes. But, confined to this earth, he does not see written in the heavens the astronomy he learns: no wonder, then, that he does not care to look at the heavens, or feel much interest in the globe, which is only an imitation of *apparent* motions. Add to this that he is frequently confused by mixing such knowledge as he has of the apparent with that of the real, and is apt to make his escape from a difficulty arising out of some wrong notion about the one, by an improper application of the other. To such a person it will be advantageous to have recourse to a book in which *nothing but appearances are treated of: which might, for anything that it contains, have been written by a follower of any school of explanation that ever existed; because it never, even incidentally, alludes to the derived doctrines of any one of them, but explains only that which passes before human eyes, or its imitation upon the globe.* The present is such a work: no expression which it contains, when ambiguous, is to be understood in any other manner than with reference to what actually appears to take place.

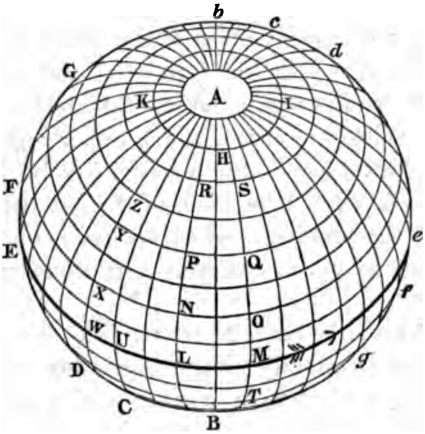
The preceding of course refers to the celestial globes, and to their original heavens. In the terrestrial globe the position is reversed. Here we have an imitation of the reality, in opposition to our senses, and to the maps, which rather represent appearances. The greatest use of the terrestrial globe is the same as that of a map, with advantage taken of the real truth of the relative situations: the problems, which are easier on the terrestrial globe than on the map, are not very numerous, nor all of the highest interest.

No endeavour will be made to crowd into this work all the problems that are frequently given: but rather to lay down the principles of the subject in a manner which will enable the attentive student to invent solutions for himself.

CHAPTER I.

Terms used in connexion with the globe—Angular measure by arc, and by time—General description of the mode of describing position on a sphere, of which latitude and longitude, right ascension and declination, &c. are subsequent particular cases--Various theorems for exercise in understanding this method.

A SPHERE or globe is made by a circle revolving about one of its diameters: whichever diameter is chosen, the same sphere is produced. The *surface* of the sphere is traced out by the *circumference* of the circle. In the figure, the fixed diameter is presented somewhat obliquely to the eye, so that only one extremity, A, is visible, the other being on the other side of the sphere: and *b*AB, *c*AC, *d*AD, &c., are parts of the revolving circle in different positions. Every possible position of the revolving circle, whether the fixed diameter pass through A or elsewhere, is one of the *greatest* circles which can be drawn on a sphere, and is therefore called (not very correctly) a *great* circle. The centre of the revolving semicircle is called the *centre* of the sphere.



Every point of the revolving semicircle traces out a circle on the surface of the sphere: thus H describes the circle HIK. Of all these circles, the greatest is that traced out by L, one of the points halfway between the extremities of the fixed diameter: and this is one of the (so called) *great* circles of the sphere. The *smaller* circle traced out by any point except L, is, as improperly, called a *small* circle. The whole system of great and small circles belonging to the diameter A*a* * have names of connexion, as follows:—A and *a* are called the *poles* of them all, and A*a* their *axis:* the circle EL*e* traced out by the point L, halfway between A and *a* on the sphere, is called the *primary;* all the small circles traced out by other points are called its *parallels;* and all the positions of the revolving circle, as *b*AB, *c*AC, &c. are called its *secondaries.* Of all the arcs contained between two secondaries, that of the primary, as LM, is the greatest: the rest, as NO, PQ, RS, diminish in magnitude as we approach one of the poles. All the points of one circle, as H, I, K, are equally distant from its pole, which may therefore be described as a sort of *spherical centre,* or centre on the sphere, to the circle. In order to describe a circle on a *solid* sphere, a pair of compasses must have one point stationary at the pole of the circle to be described. A revolution is divided into 360 equal parts, each of which is called a *degree* (of revolution): and each circle is divided into 360 equal parts, each of which is called a *degree* (of the circle). Each degree is divided into 60 equal parts called *minutes,* each minute into 60 equal parts called *seconds.* These are abbreviated as follows:—38 degrees, 29 minutes, 42 seconds, is written $38^\circ\ 29'\ 42''$.

A number of degrees of revolution is the quantity which mathematicians call an *angle:* but a number of degrees on any circle, being an *arc* of that circle, is obviously a *length.* But amount of revolution, and length of arc, are connected as follows:—Whatever degrees of revolution are moved through by the revolving secondary, the same number of degrees of arc are traced out by each of the revolving points, each on its own circle. Thus, if AL move into the position AM through one-tenth of a revolution, or 36° of revolution, then the arc LM is 36° of the great circle; NO, PQ, RS, &c. are each 36° of the small circles in which they severally lie. It is obvious that the degrees of length in different circles are longer or shorter, in the same proportion as the whole circumferences are longer or shorter.

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* A visible point on the sphere being signified by a capital letter, I designate the opposite point by the corresponding small letter. Thus *a* is placed at the other and invisible extremity of the fixed diameter.

A revolution, when made in 24 hours, is frequently divided with reference to the division of time, as follows:—The 24th part of the revolution, or of any circle made by it, is called an *hour;* its 60th part, a *minute;* the sixtieth part of that, a *second.* But still, for distinction, these new minutes and seconds are said to consist *of time:* thus, an arc of a circle will be said to be a number of hours, minutes, and seconds, of time; meaning, that the arc in question would be described in that number of hours, minutes, and seconds, if the whole circle were described in 24 hours. At this rate 15° make one hour (1^{h}), 15′ make one minute of time (1^{m}), 15″ make one second of time (1^{s}): also 1° is four minutes of time, 1′ is four seconds of time, and 1″ is one-fifteenth of a second of time.

To turn 71° 13′ 28″ into time and $5^{\mathrm{h}}\ 38^{\mathrm{m}}\ 47^{\mathrm{s}}$ into ordinary angular measure (usually called *space*, when thus opposed to time)—

For 60°	allow	4^{h}	0^{m}	0^{s}	For 5^{h}	allow	75°	0′	0″
11°	„		44^{m}	0^{s}	36^{m}	„	9°	0′	0″
13′	„		0^{m}	52^{s}	2^{m}	„		30′	0″
15″	„		0^{m}	1^{s}	44^{s}	„		11′	0″
13″	„		0^{m}	$0^{\mathrm{s}}\frac{13}{15}$	3^{s}	„			45″
71° 13′ 28″	is	4^{h}	44^{m}	$53^{\mathrm{s}}\frac{13}{15}$	$5^{\mathrm{h}}\ 38^{\mathrm{m}}\ 47^{\mathrm{s}}$	is	84°	41′	45″

The usual mode of distinguishing one point of the sphere from another is as follows:—Choose any convenient great circle for a primary, as EL*e*, and also a convenient point, U, to measure from on that circle; also find the poles of that circle, A and *a*. Then any point of the sphere, Q, is fully known in position by the following process:—through Q, the point required to be specified, draw the secondary circle AQM; measure UM and MQ, and note the way in which each falls, that is, whether M fall to the right or left of U, and whether Q fall above or below EL*e*. These four circumstances, the length and direction of UM, and the length and direction of MQ, obviously settle the position of Q on the sphere, as soon as the position of EL*e* and of U are themselves settled. It will save future trouble, and learning the same thing at least three times over under different names, if the reader now endeavour to master this part of the subject under names which will apply equally to all the systems of measurement in use. Let, then, the selected primary ELe be called the *circle of progression and regression*, and all its secondaries *circles of departure;* let the point U be the *zero of progression*, let A be the *superior* pole, and *a* (invisible) the *inferior* pole. Let the two directions on the primary, measuring from U, be called, one the direction of *progression*, the other that of *regression*, the choice being arbitrary (in the figure the arrow shows the direction I here call that of progression): and let an arc measured from U be called an arc of progression or regression, accordingly. Let an arc, as MQ, measured on a secondary from the circle of progression, be called an arc of *departure*, *superior* departure, or *inferior* departure, according as it is thrown towards the superior or inferior pole. Then it is clear that a point Q is known as soon as its progression or regression, its departure, and the name of the departure, are known relatively to any given primary, and zero-point upon it. That the reader may at once see how much the proper conception of the meaning of astronomical and geographical terms must arise from consideration of the preceding system, I give the table in the next page, to which he will do well to turn as the several terms come subsequently into our nomenclature.

The following observations may be made equally on all the cases.

Any point may be described either by its progression or regression: thus 60° of progression is 300° of regression, and either is found by subtracting the other from 360°. The progression of O, Q, or S, is UM for all, and their regression the rest of 360°: the regression of X, Y, or Z, is UW; their progression is the rest of 360°. All points which have a common progression lie on the same half of a secondary; all points on the other half of the secondary have each 180° more of progression than the points of the first half, or 180° less. All points situated on the same parallel to the circle of progression have the same departure: all the points on the circle of progression itself have no departure. Any amount of progression or regression, with 90°, or a quarter of a circle, of departure, brings us to the pole of the same name as the departure. The distance between two points on the circle of progression is the difference of their progressions, or else the excess of 360° over that difference: there are of course two ways of going from one point to another over the arc of a

When the circle of progression is the	And the zero-point is the	The superior pole is called	The inferior pole is called	Progression is called	Regression is called	Superior departure is called	Inferior departure is called	Secondaries are called	Parallels are called
Equator.*	Point through which the meridian of Greenwich passes.	The North pole.	The South pole.	East Longitude.	West Longitude.	North Latitude.	South Latitude.	Meridians.	Parallels of Latitude.
Equator.	First point of Aries.	The North Pole of the Heavens	The South Pole of the Heavens.	Right Ascension (measured Eastward.)	Never used.	North Declination.	South Declination.	Hour-circles.	Parallels of Declination.
Ecliptic.	First point of Aries.	The North Pole of the Ecliptic.	The South Pole of the Ecliptic.	Celestial Longitude, (measured Eastward.)	Never used.	Celestial North Latitude.	Celestial South Latitude.	Circles of Longitude.	Parallels of Latitude.
Horizon.	North point of the Horizon.	The Zenith.	The Nadir.†	Azimuth (measured Eastward.)	Azimuth (measured Westward.)	Altitude.	Depression.†	Vertical Circles.	Parallels of Altitude.
Horizon.	East point of the Horizon.	The Zenith.	The Nadir.†	Amplitude† (measured Northward.)	Amplitude† (measured Southward.)	Altitude.	Depression.†	Vertical Circles.	Parallels of Altitude.

* This for the terrestial globe; the others for the celestial.

† Very rarely used.

great circle. The distance between two points on the same *half* secondary is the *difference* or sum of their departures, according as those departures are of the *same* or different names. Opposite points on the sphere have departures of the same amount, and different names: but the progression of one is 180° more than that of the other. Progression may be reckoned beyond 360°, but uselessly; thus a progression of 410° is the same thing, so far as the position of a point is concerned, with one of 50°. Departure may even be reckoned beyond 90°, also uselessly; a departure of 95°, with any progression, is equivalent to 180° more of progression, with 85° (the rest of 180°) of departure. These miscellaneous propositions may serve for exercise in the mode of measurement, which is conducted as if every specified point of the sphere were bound to be gained by travelling from the zero-point along the circle of progression, until the point in question can be reached by turning off upon the secondary which passes through the point. The number of degrees thus travelled over on the circle of progression, and on the secondary, respectively, are the progression (or regression, as the case may be) and the departure.

Ths distance of a point from the superior pole is called the *co-departure*. Two angles, of which the sum or difference is 90°, are called *complements* each of the other; and co-departure is an abbreviation of *complement of the departure*. Thus AT and AS are the co-departures of T and S, MT and MS being the departures, the first inferior, the second superior.

On great circles which cut one another, the following propositions must be distinctly apprehended and accurately remembered. Any two points of a sphere, *not opposite*, can only have one great circle drawn through them: and the two arcs into which they divide that great circle are the longest and shortest *circular* lines which can be drawn between them; while the shorter of the two is also absolutely the shortest distance which can be drawn between them *on the sphere*. But an infinite number of small circles can be drawn through two points not opposite, the smallest of which is that which has its pole halfway between the two points. And all the circles drawn through two given points have their poles on a great circle equally inclined to the two sides of the great circle passing through the two points, and passing halfway between them. Thus all the circles drawn through K and I have their poles in the great circle BA*b*, &c., and the smallest of all (KHI) has its pole at A.

But two *opposite* points of a sphere can have no *small* circles drawn through them; nothing but great circles. All these great circles are secondaries to the great circle which has the two opposite points for its poles. The poles of all the secondaries lie upon the primary: if a first great circle have its poles upon a second, then the second great circle has its poles upon the first.

Any one great circle may be brought to coincide with any other by revolution about the diameter of the sphere which passes through the two opposite points in which they meet. The amount of revolution necessary to bring one circle into coincidence with the other is the *angle* made by the circles, under which name two distinct things are described. Let AC, &c. and A*g*, &c. be the two circles: and let, say 40° of revolution, bring AC, &c. into the position A*g*, &c. Then what is left of half a revolution, or 140°, would bring AC, &c. into the position AG, &c., and the circles would be brought into coincidence, with an inversion of the halves which coincide. Consequently the angle of the two circles may be called either 40° or 140°; and similarly in other cases. Again, the arc of the primary, UM, intercepted between two secondaries (and any two circles which meet are secondaries to some primary), is always as many degrees of arc as the angle between them is of revolution, as before noticed. While one circle moves into the position of the other, by revolution about their common axis, the pole of the revolving circle travels towards the pole of the fixed one, through an arc of just as many degrees of length on a great circle as there are degrees of revolution; that is, if the circles AC and A*g* are 40° of revolution apart, two of their poles are 40° of length apart, on a great circle. When it is said that the *angle* of two circles is equal to the *distance* between their poles, it is not meant that the angle, or quantity of revolution, is actually equal to the length, but that the one contains as many degrees of revolution as the other does of length. And in this sense angles and arcs are very frequently confounded, without confusion.

Let a point move in a great circle, which call its *orbit*. The orbit cuts the plane of progression in two points, which call *nodes*. At one node it passes from the hemisphere of inferior departure into that of superior; let this be called the *ascending* node, and the other the *descending* node. At the ascending node, the moving point has no departure; as progression goes on, the superior departure increases, until a point in the orbit is attained, having 90° more of progression than the ascending node : the superior departure is then greatest, having as many degrees of arc as there are degrees of revolution between the circle of progression and the orbit. The superior departure then begins to diminish, and becomes nothing when the descending node is gained: after which the same changes are repeated in the inferior part of the orbit, until the ascending node is again arrived at, and a revolution is completed.

When a point is moving on the sphere, it changes, generally speaking, both its departure and progression. Let it move on a parallel of departure, and it then changes progression only, and not departure: let it move on a secondary to the circle of progression, and it changes departure only, and not progression; except when it passes through a pole of the circle of progression, the instant after which the progression receives an accession or diminution of 180°, and the departure begins to be measured from a different and opposite point of the circle of progression. In every other case, both progression and departure are changed. There is therefore a rate of change in both: at any one instant both are changing, each with its velocity per second, per hour, or per whatever unit of time may be employed. These velocities are termed *motion in progression* and *motion in departure.* In the preceding case, in which an orbit is described by a moving point, if the motion in the orbit be uniform, that is, if equal arcs of the orbit be described in equal times, then the motions in progression and in departure are both variable, or different at different times. At the nodes, the departure is changing most rapidly, the progression least rapidly; halfway between the nodes, the progression is changing most rapidly, the departure not at all (for an instant). For instance, let the orbit be at an angle of 30° to the circle of progression, and let the point move in it at the rate of a degree an hour: then at each node, the motion in progression is 52′ per hour, very nearly; halfway between the nodes, it is upwards of 1° 9′ per hour: as to the motion in departure, it is 30′ per hour at the nodes, and nothing at halfway between the nodes. These last assertions will be better understood when the next chapter has been read.

If the pole of a great circle describe a small circle about the pole of another, the circle which has the moving pole is itself in motion, and its intersections with the fixed circle continually change their places. But the angle which the moving circle makes with the fixed circle remains unaltered, being always as many degrees of revolution as there are degrees of arc between the two poles. Thus, let the moving pole describe the small circle HIK: then the moving great circle is always inclined to EL*e* at an angle which has as many degrees of revolution as AI has degrees of arc.

When the sphere revolves about an axis, the primary of that axis and all its parallels revolve, but without change of position: that is to say, the space vacated by any arc of the primary or parallel is filled up by another arc of the same primary or parallel. The parts of these circles change places with each other, but each circle occupies only one position. The secondaries, on the other hand, change their places, each secondary moving into the position which was occupied by another secondary. All other circles change their places, but each circle always remains at the same angle to the revolving primary.

The theorems in the preceding pages have been concisely given, and intentionally so: they are intended as exercises in the conception of the main properties of the sphere, and the connexion of them with the language in which they are expressed. Until they are fully understood and easily recovered, the student cannot obtain the least command over the globe for any useful purpose.

CHAPTER II.

Motion, real and apparent—Simple cases of composition of motion—Distance, how estimated by us—Direction of revolution—Conjunction and opposition—Interval of conjunctions and oppositions.

MOTION is change of place, and must be accompanied by the idea of time; change of place without lapse of time being the same thing as occupying two or more places at the same time, which is impossible. A point or atom which moves from one position to another must move in some line (straight or curved) which joins the two positions: and every position on that line, intermediate between the first and last position, must be occcupied by the moving atom at some one instant of the time of motion.

No one of the human senses is fitted to detect the motion of its owner; motion, as motion, cannot be *perceived.** Its consequences may be perceived, and from those consequences the first thought may be that motion can be inferred. But it may be made evident that in every instance those consequences are ambiguous; they may arise equally from either of two motions. When we move forward in a carriage we have many reasons to know that we are in motion; but the phenomenon of change of place is not one of them: this may just as well arise from the earth under us and the landscape about us moving backwards, the carriage remaining fixed. When the motion is rapid and smooth, this last does appear to be the case. When we see the arms of a windmill revolve, we see exactly what we should see if the earth turned the windmill round the axle on which the arms appear to revolve. When a joint of meat turns on the spit, the perception of that fact alone is no argument against the spit being at rest: it may be that the fire, the spectator, the room, and the whole earth are turning about the spit. But if at the same time the meat is seen turning about the fire, and the arms of the windmill about their axle, there is then evidence that one or the other must be in motion, unless the spit and the axle be in the same straight line, and the two revolutions be made in equal times. Every apparent motion is one of three things: real motion in the object which appears to move; real motion in the spectator who sees the object appear to move; or a combination of both.

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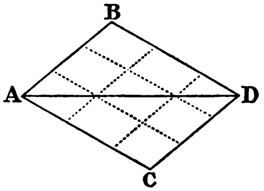
* A sentient being, placed in space, out of sight, touch, and hearing of any object, and able to tell truly and necessarily whether he is at rest or in motion, must have one more sense than we have: neither sight, touch, nor hearing would be of any avail, if there were nothing to see, hear, or touch.

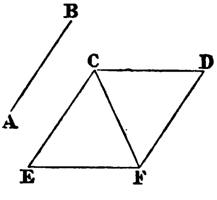
The preceding is usually expressed thus; the motion of an object, as seen, is not its *actual* motion, but its motion *relatively to the spectator*. This is true in all cases in which experience does not supply the power of substituting real for apparent motions with the rapidity of perception. It means that the spectator conceives himself to be at rest, and gives to surrounding objects, as if it were all real, the motion necessary to make all the changes of distance and direction, which, come how they may, he actually sees taking place. To understand this point, which is necessary not only for the comprehension of the real motions of our system, but even of the representation of the apparent ones on a globe, recourse must be had to explanation of the *composition and decomposition* of motion.

And first of motion in a straight line. Let a point move uniformly, that is, let equal lengths be described in equal times, and let 10 miles be described in an hour. Then the point is said to have a *velocity* of 10 miles an hour. This velocity may be imagined to result from two other separate and independent velocities in as many ways as we please. The space in which the point moves may be imagined to take one motion, and the point another motion in that space. Thus, a vessel going down a river at ten miles an hour may be carried four miles by the tide, and the other six by its own motion on the water: or the tide may be coming in at three miles an hour and the vessel moving thirteen miles an hour against it. In this manner one *resulting* velocity may be considered as the joint effect of two or more *components* arising from different causes, and each contributing to or subtracting from the joint effect. And it is to be noticed that subtractive velocities are termed components as well as additive ones; thus, when there are 3 miles of tide against the vessel, and 13 miles of its own motion, the resulting ten miles an hour is said to be compounded of both; for both are concerned in making the result what it is. This warning is necessary, for usually composition implies putting together, and will not apply to subtraction or removal.

It is easy, by a notion similar to the above, to illustrate all cases of compound motion. Let an atom move upon a sheet of paper, which sheet of paper itself moves upon a fixed table. The actual motion of the atom upon the table is then properly said to be compounded of its motion upon the paper and the motion of the paper on the table. When both motions are in the same or opposite directions, it is obvious that the resulting velocity is the sum or difference of the components, and that in the latter case it is in the direction of the greater of the components. Now consider two motions in different directions. Let A be the position of the atom at the moment in question, and let it move from A to B on the paper, while the point A of the paper is carried from A to C. When the atom arrives at B on the paper, the line AB of the paper has arrived at the position CD, and the twofold motion has occasioned the atom to be carried along AD on the table. Now AD is the diagonal of the parallelogram ABCD; and the velocity and direction of a compound motion, arising from two uniform rectilinear motions, is represented by the diagonal of the parallelogram of which the component motions are represented in velocity and direction by the sides. This one proposition is the key to the phenomena of relative motion, as follows:—



The spectator moves, say from A to B in one minute, uniformly, while the object he looks at does the same from C to D. Give the whole ground on which both motions take place a motion of its own in any direction, and it is obvious that no alteration will take place in the motion of the object relatively to the spectator. Let then the ground take a motion equal and opposite to that of the spectator; the latter will then be absolutely at rest, for while he advances on the ground, the ground moves as much backwards. He will *be* then as, if the motion be smooth, he *fancies he is*, namely, at rest. Now while the object moves from C to D, the line CD itself comes into the position EF, by the motion of the ground, CE being



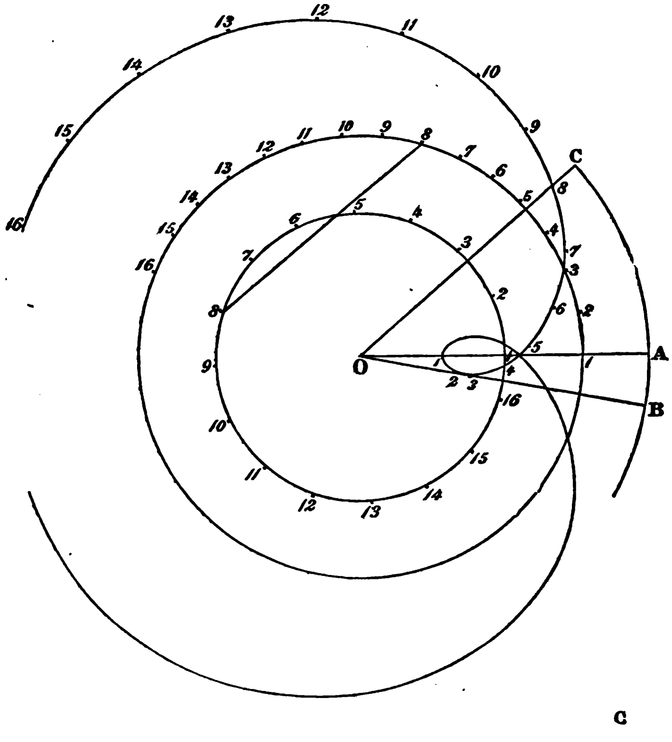
equal and parallel to AB. Hence, C moves over CF, the diagonal of the parallelogram CDEF, and this line CF, which is what C would describe if motion were communicated to the whole ground such as would reduce A to rest, is the line which C appears to describe to A, who imagines that he is at rest. Hence the rule for apparent motion is—Combine with the real motion of the object a motion equal and contrary to that of the spectator: the result is the apparent motion of the object to the spectator.

If the motion of the object be exceedingly rapid compared with that of the spectator, a diagram will show that its apparent motion is very nearly the same as its real motion: the greater CD compared with CE, the more nearly does CF coincide in magnitude and direction with CD. The rays of light move so quickly, that no motion *on* the earth can alter sensibly the apparent direction at which they pour into the eye. But the motion *of* the earth is rapid enough to do this to a very small extent, which produces in the stars the effect called *aberration*.

It is not necessary that the body should actually move for a second, or the spectator either. Let there be but an instant's start, as it were, a momentary commencement of motion, instantly checked, but let it take place in the spectator as if he would move over AB in one second, and in the object as if it would move over CD; then, the spectator, being unconscious of his own motion, will see the object take a start towards F, as if it would reach F in one second.

A young student has some difficulty in obtaining an exact notion of velocity, independent of any particular space moved over. A stone falls 16 feet in the first second, that is, if dropped from a height of 16 feet, it reaches the ground in a second. But it shocks the ground with the momentum due to a velocity of 32 feet per second. Not that it moves over 32 feet in a second, nor that it moves at the rate of 32 feet per second for any time at the end of the second; but because, as the end of the second draws on, the rate of motion becomes nearer and nearer to that which would, if continued for a second, give 32 feet. For instance, in the last hundredth of a second, it does not move over *exactly* the hundredth part of 32 feet, but very near it. The hundredth part of 32 feet is 3 inches 84 hundredths of an inch; the space moved over in the last hundredth of a second is 3 inches 82 hundredths of an inch. The practical rule for finding, or rather for forming a conception of, velocity is, take the motion for a very small time near the point in question, consider it as uniform, and find by the rule of three how much would be described in a second at that rate. The theoretical rule is, let there be no limit to the smallness of the time taken, and ascertain the limit towards which the result of the preceding rule perpetually approaches as the time is taken smaller and smaller.

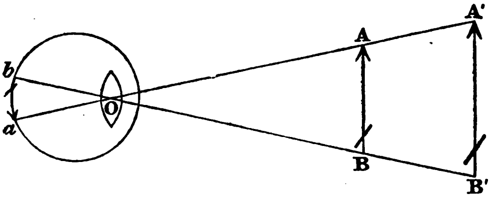
The spectator moves in a curve, and the object also: required the apparent curve in which the object moves, the spectator imagining himself at rest. Take a good number of simultaneous places on both curves, and join them by straight lines; take a fixed point, and set off from and about it lines of the same length, and in the same directions, as the lines which join the simultaneous positions: the extremities will show the figure of the curve apparently described by the object. For instance, let the object revolve in an outer circle, less rapidly, and the spectator in an inner circle, more rapidly. When the spectator is at 1, 2, 3, 4, &c. of the inner circle, let the object be at 1, 2, 3, 4, &c. of



the outer circle: then while the spectator moves from 1 to 16 on the inner circle, and the object from 1 to 16 on the outer, the object appears to the spectator, imagining himself fixed, say at O, to describe the looped curve 1, 2, 3, 4,...16, the unmarked part of the curve being the apparent motion of the object during the spectator's previous revolution. This curve of apparent motion is constructed as follows. When the spectator is at the inner 8, the object is at the outer 8; and from O to 8 on the looped curve is a line of the same length and direction as 8 8 joining the two circles; and similarly for the other points. Now the apparent place of the object depends solely on its distance and direction, and the looped curve is a register of successive apparent places and directions, all constructed with reference to the fixed point O. Let the spectator imagine himself fixed, and, unless his eyes deceive him about direction and distance, he must attribute to the object motion in the looped curve.

Now the eye does deceive us about distance; or rather, at very great distances, it does not give information about change of distance with sufficient rapidity. Examine the flight of a bird at a very great distance, at which the parts of its body cannot be distinguished: if it be moving directly to or from us, it is some time before we can tell which of the two it is. Change of direction we can readily perceive: the axis of the eye must be altered as much to perceive a certain amount of it, whether the object be ten yards off or a thousand miles. When distances become immensely great, as in the case of the heavenly bodies, we lose altogether the correct idea of distance, and are deprived of all power of noting changes of distance. The brighter bodies seem the nearer, generally speaking; and we try to form ideas of distance by looking at the heavenly bodies with the associations derived from our knowledge of terrestrial objects. It therefore concerns us to inquire what these associations are.

When we *see*, we receive the impression which a painting on the choroid membrane of the eye makes upon the network of the optic nerve (the retina) which is distributed in front of that membrane. This painting is an image formed by the rays which pass through the lenses of the eye from external objects, and may well be likened to the image formed in a *camera obscura*. Let this painting come upon the choroid membrane, no matter how, and the object is *seen*. Let supernatural power, or force of imagination, produce upon the retina the *effect* of the painting on the choroid, and the appearance of an object is produced as vividly, it may be, as if the object were actually present. Now this painting is only a painting, and it is perfectly possible that the same painting may come from different objects. Either of the arrows AB or A'B' would produce the same painting *ab* on the choroid, if there were no loss of light while rays pass from A' to A, &c. As long as the angle AOB remains the same, the object may be placed further off or nearer in that angle, without any effect being produced on the size of the painting *ab*.



This angle bears the name of the *apparent magnitude* of the object, and the idea which we form of the real magnitude is not one which is necessarily conveyed with the first gift of sight, but is gradually made out by the help of experience. Light is lost in passing through the air; distant objects therefore appear more dim than nearer ones, other things being equal. We learn, by looking at the same object at different distances, to know how distance affects brightness, and we carry our experience with us to the view of other objects. But when we come to look at the heavenly bodies, the application of our associations leads us wrong. We have no other experience of bodies at such immense distances, or gifted with such brilliancy, intrinsic or derived; and we place them in our minds at capricious distances, depending upon the state of the intermediate air; mixing up ideas derived from the great magnitudes which we know they must have with the perception of the angles under which we see them. A sovereign held at eight feet distance from the eye is of the same *apparent* size as the sun: this is almost incredible, but it is certainly true. The sun and moon are nearly of the same apparent size, but the moon seems the nearer of the two, though not the brightest. The reason is that the moon's edge is more distinctly visible than that of the sun, so that it resembles a nearer object. On a clear night it is hardly possible, with the eye fixed on the moon at full, to assent to the idea of her distance being 250,000 miles.

Of the *changes* of distance of the heavenly bodies we can *see* nothing. An astronomer, who measures the angle under which the moon is seen, may *know* that her distance varies, but not by perception alone. When changes of distance are not seen, apparent motion resembles a real motion performed upon a globe the centre of which is at the eye: motion to or from us is insensible, only motion round us is seen. Returning to the figure, let us suppose the spectator to think that the object is at A, when it is at 1 in the looped curve, he imagining himself to be at O. Then the apparent course of the object, while it goes, relatively to himself, through 1, 2, 3, 4, 5, 6, 7, 8 in the looped curve will be, if it be too far off to note changes of distance, from A down to B, where it will appear to rest a little while, and then it will turn and move along BAC.

We now begin to see what is meant by the *globe of the heavens.* There is no such thing: the celestial bodies are not situated on any globe, but all the motions we can see are such as might take place on a globe. We are unable to form an idea of their distances; we can see no changes, but changes of direction: and all these changes of direction can be represented by change from one point to another of a globe. This will afterwards be further developed.

When an object revolves, or appears to revolve, in a circle, it is obvious that there are two distinct ways of doing it: two bodies so revolving may come together by one overtaking the other, or by one meeting the other, which is usually expressed by saying that they are revolving in the same or in opposite *directions.* There is some confusion about this use of the word direction: a body revolving in a circle takes every possible direction in the course of a revolution, and another body, revolving the contrary way, also takes the same directions as the former, but at opposite points of the circle. It is rather a misuse of language to say that if two objects be at opposite points of a circle, revolving in the same directions, they are moving in opposite directions: and yet this must be said by those who speak in usual phraseology. It is by precisely a confusion of the same sort that in driving, the left side is right, and the right side wrong; namely, by the use of a word in two different senses. Direction of revolution is one thing, direction of motion another; there are but two directions of revolution, there is an infinite number of directions of motion. As we have much to do with the former, and very little with the latter, we need not invent a distinction: but the reader must take good care to avoid any confusion between the two. He may test his understanding of the word direction by the following proposition, which ought to be readily seen. If a luminous body revolve on a globe, and if there be an opaque object at the centre, the shadow on the opposite side of the globe will always have the same direction of revolution as the luminous body, but an opposite direction of motion.

Two bodies are in *conjunction* when they are at the same point of a circle, and in *opposition* when they are at opposite points. When two bodies revolve in the same direction, the interval between two conjunctions is longer than the time of revolution of the quicker body, and so is the interval between two oppositions: but when they revolve in opposite directions the interval between two conjunctions (or oppositions) is less than the time of revolution of either. If one revolve very slowly, the interval between two conjunctions is little more than the time of revolution of the quicker. To find the interval of two conjunctions, reason as follows:—1. If the bodies revolve in the same direction. Say A revolves in 10 minutes, B in 7 minutes. It is clear that in 70 minutes there will be a conjunction at the point they set out from, A having done seven revolutions, B ten. In this time B has gained *three* whole revolutions upon A. But the *next* conjunction takes place when B has gained *one* whole revolution upon A, that is, in the third part of 70 minutes, or $23\frac{1}{3}$ minutes, when A has made $2\frac{1}{3}$ revolutions, and B $3\frac{1}{3}$ revolutions. The rule is:—Divide the product of the times of revolution by their difference, and the quotient is the interval of the conjunctions. Another example:—What is the interval between two conjunctions of the minute and hour hand of a watch? The minute-hand revolves in one hour, the hour-hand in 12 hours; the product of 1 and 12 divided by their difference, and called hours, is $1\frac{1}{11}$ hours, or 1 hour, 5 minutes, 27 seconds, and $\frac{3}{11}$ of a second. 2. If the bodies revolve in opposite directions. Say A revolves in 10 minutes, B in 7 minutes. It is clear that in 70 minutes there will be a conjunction at the point they set out from, A having done seven revolutions, B ten. In this time A has separated from B *seventeen* whole revolutions. But the *next* conjunction takes place when A and B have separated by *one* whole revolution, that is, in the seventeenth part of 70 minutes, or $4\frac{2}{17}$ minutes, when A has made $\frac{7}{17}$ of a revolution, and B $\frac{10}{17}$ of a revolution. The rule is:—Divide the product of the times of revolution by their sum, and the quotient is the interval of the conjunctions. Another example:—What would be the interval between two conjunctions of the minute and hour hand of a watch, if they revolved in opposite directions? The minute-hand revolves in one hour, the hour-hand in twelve hours; the product of 1 and 12 divided by their sum, and called hours, is $\frac{12}{13}$ of an hour, or 55 minutes, 23 seconds, and $\frac{1}{13}$ of a second.

By the *first* of the preceding rules, the following questions are also solved:—Given the interval of conjunction, and the quicker time of revolution, required the slower, when the bodies revolve in the same direction, and—Given the interval of conjunction, and either time of revolution, to find the other, when the bodies revolve in opposite directions. By the *second* of the preceding rules, the following is solved:—Given the interval between the times of conjunction, and the slower time of revolution, required the quicker, when the bodies move in the same direction.

When a globe revolves about one of its diameters, each extremity of that diameter is called a *pole of revolution*. Every point of the sphere describes either the great circle which has the poles of revolution for its poles, or one of the parallels of that great circle. All the secondaries of that great circle are interchangeable; that is to say, each of them no sooner shifts its position than another takes its place. And all circles are interchangeable, which, being equal, have their poles upon the same parallel of revolution.

CHAPTER III.

The terrestrial globe—Its description, and use in problems which do not directly involve astronomical considerations—Latitude, longitude, distance, and circular bearing of places—Points of the compass—Magnetic variation—Length of degrees of longitude.

As before observed, in the globe of the heavens we try to represent appearances, however little those appearances may indicate realities; while in the globe of the earth, we stick to realities in spite of appearances. For this and other reasons, we shall separate entirely the descriptions of the two.

The earth is really a slightly flattened sphere, having the *axis* which passes through the poles the shortest of all its diameters. This axis, continued, forms the axis round which the heavens appear to revolve. The shortest radius, or semidiameter, being half the axis, is 3949 miles; the longest, which belongs to the great circle, having the ends of the axis for its poles, (called the *equator*) is 3962 miles. On a globe of eighteen inches diameter, this difference of 13 miles would not amount to so much as the thirtieth of an inch, and it would be altogether useless to take any account of it. We shall then suppose the earth to be a sphere with the mean semidiameter of 3956 miles, so that, roughly speaking, 1000 miles are 2¼ inches (more accurately 2·275 inches*). The mountains are not represented; one of thirteen miles high (and we know of none such) would not prick the fingers through the varnish with which the globe is covered, which therefore much more than represents a universal deluge. Supposing the atmosphere to be 40 miles high, it would nowhere rise a tenth of an inch from the globe.

The mean arc of one degree on a great circle of the earth is 69 miles in length, from which it varies slightly, being about

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* Any one who does not know decimal fractions may read them, at least, by remembering that the figures which follow the point are successively tenths, hundredths, thousandths, &c. of a unit: thus, 1234·7678 inches means 1234 inches, 7-tenths, 6-hundredths, 7-thousandths, 8 ten-thousandths of an inch.

3-10ths of a mile more at the pole, and as much less at the equator. In distances measured near the equator, subtract 1 in 200 from the result of the 69 miles per degree, and the truth will lie between the two results, but nearer to the latter.

Great Britain is said to contain 84,000 square miles. If this be so, it is about such a fraction of the whole surface of the globe as one penny is of ten pounds. The earth being a globe of 18 inches diameter, the moon is one of 5 inches diameter at 45 feet distance; and the sun is a globe of 167 feet in diameter at a little less than 3¼ miles distance.

The delineation of the parts of the globe, the distinctions of land and water, the method of denoting mountains, rivers, lakes, towns, boundaries, &c. &c., are presumed to be familiar to the reader; few desire to study the globe who have not previously used maps. The political divisions are useless for any *scientific* purpose whatever; the natural divisions, for any *mathematical* purpose. The apparent diurnal revolution of the heavens, made about an axis which passes through the centre of the earth, is the foundation of our measures of relative position on the earth. Let the reader now review pages 6—9, and satisfy himself that he has a sufficient idea of assignment of position by progression and departure. We now proceed to explain the first line of the system of applications in page 8.

The axis round which the heavens appear to turn, passing through the centre of the earth, cuts the earth in two opposite points; these opposite points are the poles of a certain great circle: this great circle is called the *equator*, and its poles being of more consequence and more frequently mentioned than those of any other circle, are called the poles of the *earth*, not the poles of the equator merely. One of them is called the *north* pole, the other the *south*. There is no mathematical mode of defining this distinction: the north might be made south and the south north without any inconvenience except overturning established usage. The north pole is that which is on the same side of the equator with ourselves; the south pole is the other one. Again, a person looking towards the north, or placing his face so as to look along the secondary to the equator which passes between his feet, and towards the north pole, has the east on his right hand and the west on his left. The distinction of right and left is as arbitrary as that of north and south; the side of a man on which the heart is placed is the left side, and the other is the right.

The great circles which pass through the poles, the secondaries to the equator, are called meridians: more properly, each half of each circle is one meridian, and each circle is composed of two opposite meridians. Thus, if a line be traced direct from the north to the south pole so as to pass through Greenwich, that line is the meridian of Greenwich; the other half of the circle, by which we go from the south pole again to the north on the other side, is the opposite meridian.

That which is called progression in page 7 is in the system before us called *longitude*, and departure is called *latitude*. A point must be taken at pleasure on the equator, from which to measure longitude: for though the equator itself is marked out by nature as the most convenient circle of progression and regression, no particular point on it is of more consequence than another. We accordingly, in this country, choose, for the zero of progression, the point at which a meridian drawn through the observatory at Greenwich cuts the equator. Let A (page 4) be the north pole, AU, &c. the meridian of Greenwich, EL*e*, &c. the equator: the arrow then shows the easterly direction; the point O has UM° of east longitude, and MO° of north latitude; T has the same longitude, but MT° of south latitude. We here mean by UM° the number of degrees of arc in UM. Similarly X has UW° of west longitude, and WX° of north latitude.

The imitation* of the earth, which we call the *globe*, turns on an axis, the pivots of which are in a hoop of brass, called the *brazen meridian*, or frequently *the* meridian. This meridian rests in a wooden hoop, to which the name of the *horizon* is given, somewhat improperly, as we shall presently notice. This brazen hoop is supported at its lower part by the stand of the whole apparatus, but not fixed, in such a manner that it may be freely turned in a vertical plane, so as to make any point of it highest. This power of turning the brazen meridian round makes the terrestrial globe serve some astronomical purposes, but its most essential use, in this present chapter, in which we insert no astronomical problem, is to bring the different parts of the globe into convenient positions.

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* The term *globe* is frequently applied to the earth itself, but never in books on the use of the globes. Nevertheless, it has sometimes happened to beginners to apply statements to the earth itself which were only written of the pasteboard and paper model of it. We have heard some persons say that they had in their youth an indistinct idea of there being a *brazen meridian* surrounding the earth, which they wondered that they never saw.

Note that the globe is carefully hung so that its pivots of rotation may be on the *eastern edge* of the brazen meridian, and not at any depth within the hoop: so that the eastern edge is the true secondary to the equator.

Agreeably to our definition of a meridian, the brazen meridian is a couple of opposite meridians. It will be observed that these two meridians are differently graduated: on one side the graduations are on the under edge, and 0, 10, 20, &c. are reckoned from the equator; on the other the graduations are on the upper edge, and 0, 10, 20, &c. are reckoned from the pole. The first is always to be used when places on the globe are to be brought to the meridian; the second when the globe, meridian and all, is to be elevated or depressed in an astronomical question. Both graduations go to half degrees.

The equator on the globe, the broad line which always passes through 0 on the meridian, is divided into degrees and quarter degrees of longitude. There are three reckonings. The first carries longitude eastward all round the globe, from 0 to 360°. The second carries longitude westward as far as 180° only: thus, at 5° of longitude further than 180°, we see 185° (east longitude) or 175° (west longitude). The third is in time, (page 6) and goes twelve hours each way, east and west, with a double reckoning, counting hours both from 0° of longitude, and from 180°. The quarters are marked out by crosses, and each five minutes by a dot. For greater accuracy the conversion of degrees into time must be used (page 6). The other broad circle, the *ecliptic*, is astronomical, and will be hereafter described, as also the *Analemma*.

The wooden *horizon*, so called, is more appropriately thus named when the globe is celestial. On the terrestrial globe it is merely the means of indicating the great circle which has for its poles the highest and lowest points of the globe for the time being. Its upper surface is marked with various circles, as follows. The inmost of all is merely a great circle divided into degrees and quarter degrees, with a double reckoning. The inner one proceeds from the east and west points, and is called *amplitude*; the outer one from the north and south points, and is called *azimuth*. In the next circle are the points of the compass, in the next the astronomical signs of the zodiac, which still preserve their importance upon globes, though the astronomical use of them is obsolete. It would be unwise to omit them from globes, which are often referred to on questions arising out of old books, and expressed in old language. At the outer edge of the signs of the zodiac is another graduation, which cuts each sign of the zodiac into 30 degrees, and each degree into four quarters. The rest of the horizon is devoted to a graduated circle, irregularly divided into 365 parts, in such a manner that the days of the month come against the degrees of the zodiac in which the sun is for those several days. Let the reader find out for himself that the intervals are here wider in January than in June. The little figures which he sees sideways belong to the *equation of time* hereafter described.

The east and west points of the horizon ought always to be exactly opposite to the equator: nevertheless on looking at one of them from above, it will appear to fall below the equator. But if the eye be brought down to a level with the horizon, so as to look along its upper surface at the east point, it will then be clear that the line which marks out the east point would, if lengthened, exactly pass through the middle of the broad line representing the equator. The same difficulty occurs as to the brazen meridian, in fixing exactly the part of the globe which is under it. If one of the printed meridians on the globe be brought exactly under the brazen meridian, so that it shall be quite even with the eastern or graduated edge when the eye is exactly above both, then when the eye is moved towards the east it will seem certain that the printed meridian is eastward of the brazen one. It is a good plan to take a bit of card or thick paper, which will not scratch the globe, and hold it flat upon the brazen meridian, bringing up the printed meridian until it touches the card: it is also a safe way to keep the eye directly over the eastern edge of the brazen meridian, and then to bring up the printed meridian, degree of the equator, or mark of the place to be examined, until it is just seen along the same eastern edge.

At the north and south poles are seen small brass circles, moveable, and divided into hours and quarters. The use of them will appear when we come to astronomical problems. Call them the *brazen parallels.*[*]

With the globe is furnished a flexible graduated slip of brass, having a clamp at one end by which it can be fixed to the brazen meridian. By this the distance from one point of the globe to another can be obtained in degrees of arc. It is usually called the *quadrant of altitude*, but other arcs besides altitudes may be measured with it, and it is sufficiently distinguished by calling it the *flexible arc.*

We now proceed to such problems as simply relate to position and distance on the globe.

To find the latitude and longitude of a point on the globe. Bring the point to the brazen meridian, and the latitude is seen marked upon that meridian: look at the point of the equator which comes under the brazen meridian, and the longitude is seen marked on the equator. *To find where a place is, knowing its latitude and longitude*, bring the degree of longitude on the equator up to the brazen meridian, then look along the meridian northward or southward, according to the name of the latitude, and under the degree of latitude is the place. EXAMPLE. Required the latitude and longitude of Madras, supposed to be known to be in India, of which the general position is known. Find India, and then Madras, and bring the latter just under the brazen meridian. The latitude, as seen above, is the least trifle more than 13° north, and the longitude is 80¼° east. To turn 80¼° into time (which all astronomers now use), allow 5^h for 75°, 4^m for each of the remaining 5°, and 1^m for the quarter-degree: $5^h 21^m$ in all. This may be done without calculation, by reading the last five minute dot on the globe, and allowing each subsequent quarter-degree to count as one minute. According to the most recent observations, the latitude of Madras Observatory is 13° 4′ 9″ north, and its longitude 5^h 21^m 4^s east of Greenwich.

EXAMPLE 2. There is an observatory in lat. 33° 56′ south, long. 1^h 13^m 55^s east of Greenwich. What part of the world is this in? Bring 1^h 14^m east (we can hardly distinguish 55^s from 1^m on an eighteen-inch globe) to the brazen meridian, and just short of 34° south on the brazen meridian will be found Cape Town, Cape of Good Hope. The observatory is about two miles north of Cape Town.

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[*] They are frequently called *hour-circles*, but this name would create confusion between them and the hour-circles, or secondaries to the equator, in the celestial globe.

To find places having the same longitude as a given place, bring the given place to the brazen meridian, and cast the eye from one pole to the other along the edge on which the given place is. To find places having the same latitude as a given place, bring the given place to the brazen meridian, and then turn the globe, and note what places pass under or between the degrees which the given place lay under or between at the beginning. It is not likely that many places will be found exactly at the same longitude or latitude as the given place; a moderate degree of nearness will serve the purpose.

Example. What are the places which are nearly in the same longitude as Rome, and nearly in the same latitude as London? Answer. The west of Iceland, Trondhem, Carlstad, Berlin, Munich, Venice, the west point of Sicily, Tripoli, Loango, and Cape Frio, are nearly in the longitude of Rome; Antwerp, Cassel, Warsaw, Saratov, Orenbourg, Nertchinsk, south point of Lake Baikal, of Kamskatka, and of Hudson's Bay, the north point of Newfoundland, are nearly in the same latitude as London. Venice is west of Rome, and yet Rome is on what must be called (of the two) the western side of Italy, and Venice on the eastern. This is a confusion of language which must occur when eastern and western, northern and southern are applied vaguely: thus Trinidad, on the southern coast of Cuba, is more to the north than Baracoa, on the northern coast.

The distance from one place to another may be taken in degrees by the flexible slip, and converted into miles at 69 miles per degree. But this slip is frequently difficult to use, and cannot measure much beyond 90°. A simple table is given in the appendix, which, with a few additions and subtractions, will give distances within a few miles, and has various other uses.

This table contains numbers written opposite to all angles, increasing by 10′, from 0 up to 180°; and to each number are two angles. But it is to be understood that to get the proper number for the larger angle we are to subtract the number in the table from 200,000. Thus one line of the table is

| 68° 20′ 111° 40′ | 63079 |

Here 63079 is the proper number for 68° 20′; subtract it from 200,000 and we have 136921, the proper number for 111° 40′. These numbers are what a mathematician calls *versed-sines* of the angles or arcs, and others* may do the same. For arcs or angles greater than 180°, subtract from 360°; thus for 200° use the versed-sine of 160°.

To find the distance of two places of known latitude and longitude, proceed as follows :—

(*a*) Take which you please of the latitudes from 90°.

(*b*) Take the other latitude from 90°, if the two be of the same name (both north or both south); add it to 90°, if the two be of different names.

(*c*) Take the sum of the results of the two last: (*d*) take their difference.

(*e*) Take the difference of the longitudes, if of the same name (both east or both west), and their sum if of different names.

(*f*) Take the sum of (*d*) and (*e*): (*g*) take their difference.

(*h*) Take the sum of (*c*) and (*e*) : (*i*) take their difference.

Take twice the sum of the versed-sines of the results of (*c*) and (*d*), to which add the versed-sines of (*f*) and (*g*); subtract the sum of the versed-sines of (*h*) and (*i*); divide by 4, and then proceed as follows :—If the final result be less than 100,000, find it, or the nearest to it, in the table, and take the smaller degrees, &c., opposite for the arc: but if it be greater than 100,000, subtract it from 200,000; find the remainder, or its nearest in the table, and take the larger degrees, &c., opposite for the arc.

EXAMPLE 1. Required the distance from Petersburg (lat. 59° 56′ N., long. 30° 19′ east) to Madras (lat. 13° 4′ N., long. 80° 16′ east). Call the latitudes 60° and 13°, and the longitudes 30° 20′ and 80° 20′, being the nearest to them in the table. Then

(*a*) gives 30°, (*b*) 77°, (*c*) 107°, (*d*) (47°), (*e*) 50°, (*f*) 97°, (*g*) 3°, (*h*) 157°, (*i*) 57°.

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* We have observed that many persons are unwilling to attempt what they could as easily do as add three numbers together, because some mathematical terms are employed. To be consistent, they should refuse to wear watches until they understand the works.

The versed-sine of 107° is 200,000 diminished by 70763 (from the table), or 129237; that of 47° is 31800; of 97° 200,000 diminished by 87813 or 112187; of 3° 137; of 157° 200,000 diminished by 7950, or 192050; of 57° 45536. Now as follows:—

(*c*)	129237	(*h*)	192050
(*d*)	31800	(*i*)	45536
Add	161037		237586
	2		
	322074		
(*f*)	112187		
(*g*)	137		
Add	434398		
	237586		
4)	196812		
	49203		59° 30′

Here the answer 49203 is less than 100,000, and the nearest to it in the tables is 49246, opposite to 59° 30′. At 69 miles per degree, we have 4071 miles for 59° and 35 for half a degree (not standing upon our process as coming within half a mile), or 4106 miles for the distance required. If the distance between the two places be measured with the flexible arc, it will be found more than $59\frac{1}{4}°$ decidedly, and less than $59\frac{1}{2}°$. Measuring computed distances with the flexible arc is the best test of the goodness of a globe: a figure not at all truly globular might, from its own meridian and equator, give very good longitudes and latitudes, just as a map does, which has no pretension to globular figure. It is even possible that serious defects of position, if they were such as to affect all parts of the same parallel equally, might be hidden by a corresponding alteration of the graduations on the brazen meridian. But when one and the same flexible arc gives true distances, agreeing with previous computation, on all parts of the globe, it is impossible that any serious defect, either of globular figure or of position on the globe, can exist.

For a second example, let it be required to find the distance from lat. 48° 20′ N., long. 56° 30′ W., to lat. 24° 10′ S., long. 63° 50′ E.

(*a*) 41° 40′; (*b*) 114° 10′; (*c*) 155° 50′; (*d*) 72° 30′; (*e*) 120° 20′; (*f*) 192° 50′; (*g*) 47° 50′; (*h*) 276° 10′; (*i*) 35° 30′

	360°	(*c*)	191236	(*h*)	89258
	192° 50′	(*d*)	69929	(*i*)	18588
for (*f*) use	167° 10′	Add	261165	Add	107846
	360°		2		
	276° 10′		522330		
for (*h*) use	83° 50′	(*f*)	197502		
		(*g*)	32871		
		Add	752703		
			107846		
		4)	644857		
		Take	161214		
		From	200000		
			38786	127° 40′	

For 127° allow 127 times 69, or 8763 miles: for every minute it will be near enough to allow a mile, with a mile over for every six minutes, or 46 miles for 40′; whence 8809 miles* is the distance.

The highest point of the brazen meridian is always in that latitude which is marked out by the division *on the upper edge,* which comes against the wooden horizon. To make any point of the globe the highest, let the brazen meridian be raised or lowered until its latitude is read at the horizon on the upper divisions, and then let the globe be turned until the place is on the brazen meridian. It is then highest; the *antipodes* (or opposite† point of the globe) are lowest, and all the places which are half-way between the place and its antipodes, or which are at 90° distance of arc from both, are seen along the wooden horizon. In fact the place and its antipodes are thus made poles‡ to the wooden horizon. This is called rectifying the globe for the latitude of the place, and elevating the pole by the latitude of the place. For instance, the latitude of London is 51¼° N.: move the brazen meridian until 51¼° of the upper divisions (reckoned from the north pole) comes on the wooden horizon, and then bring London on the brazen meridian. All that part of the earth which is nearer to London than to its antipodes, is then seen above the wooden horizon: it contains all Europe, all the continent of Asia except a piece of Cochin-China and the Malay peninsula, all Africa, and North America, and South America down to the beginning of the narrower part on both sides. To form an idea of the very unequal* manner in which land and water are distributed, rectify the globe for the antipodes of London, that is, elevate the south pole by 51½°, and bring 180° of longitude on the brazen meridian: all that will be seen above the horizon is much the smaller portion of South America, Australia, the Indian Archipelago, the pieces of Asia above-mentioned, and the mass of little islands called Polynesia. Probably not one-hundredth part of the human race is found on this half of the earth.

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* The reader who has a slight knowledge of tables can apply interpolation, and come nearer than 5′, which is about the utmost error of the preceding method: but I have not thought it advisable to introduce this correction for the beginner.

† Antipodal places have opposite longitudes and latitudes both: opposite longitudes differing by 180°. Thus the antipodes of 24° N. lat., 37° W. long., are in 24° S. lat., 143° E. long.

‡ Remember the meaning of the poles of a great circle (page 5): the poles of the equator (*the* poles), important as they are, are only the poles of one circle.

When the flexible arc is clamped to the brazen meridian at the latitude of a place (one of the sides of the clamp has a sloping or bevelled edge, which must be brought† against the required degree on the meridian), and when the place is brought to the meridian, then on turning round the flexible arc (which revolves under the clamp) all the places may be ascertained which are at any given number of degrees from the given place. Only, since the numbering of the degrees on the arc goes backwards from the clamp (exactly under which is 90°), it is requisite to subtract the degrees of distance from 90°, to read distances properly. Thus, to find all the places which are 3000 miles from London: divide 3000 by 69, and we have 43½, the number of degrees; which deducted from 90°, gives 46½°. Fix the bevelled edge of the clamp at 51½°, the latitude of London, and bring London to the meridian: make the flexible arc then revolve, and it will be seen that 46½° on the arc passes across Tartary, Persia, Arabia, &c., emerging from Africa near Sierra Leone, and entering America at the Western Point of Nova Scotia.

The following problems are sometimes proposed; given one of the two, longitude or latitude, and the distance from a given place, required the other. For instance, what place in longitude 62° east of Greenwich, if any, is 3000 miles from London. Having done as in the last question, it will soon appear that 46½° in the clamp cuts the meridian of 60°, which is *marked* on the globe, in Tartary near the boundary of Persia. But to say where it cuts the hour circle of 62°, which is not marked, is not so easy, and can only be guessed at. And if we bring 62° on the equator to the brazen meridian, and endeavour to find out by the flexible arc what point of the brazen meridian is 43½° from London, it will not be so convenient as by the last method. When the flexible arc is clamped to the meridian, its other end may be pushed between the wooden horizon and the globe, and thus kept conveniently on the globe. If 62° of E. longitude be brought on the brazen meridian, and if the flexible arc be then passed under the meridian, and 0° being upon London, 43½° be brought to the eastern edge of the meridian, the point which is in longitude 62° east, at 3000 miles distance from London, will be found. But though found, it will not be well seen; there will be too much brass in the neighbourhood: and the guess from the preceding method will be as accurate and more easy. And this first method is the only one which can be conveniently applied to the same problem, when it is the latitude of a place which is given, and its distance from a given place, from which to find the longitude.

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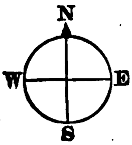
* Since globes take dust more on the upper than the lower parts, it would be wise to keep the south poles of both uppermost when they are not in use.

† In clamping, when the bevelled edge is well placed, and full against the meridian, press the upper part of the clamp firmly downwards against the meridian with one hand, while the other turns the screw. Never introduce the flexible arc within the wooden horizon until the clamping is finished, as a slip of the hand might make the arc scratch the globe.

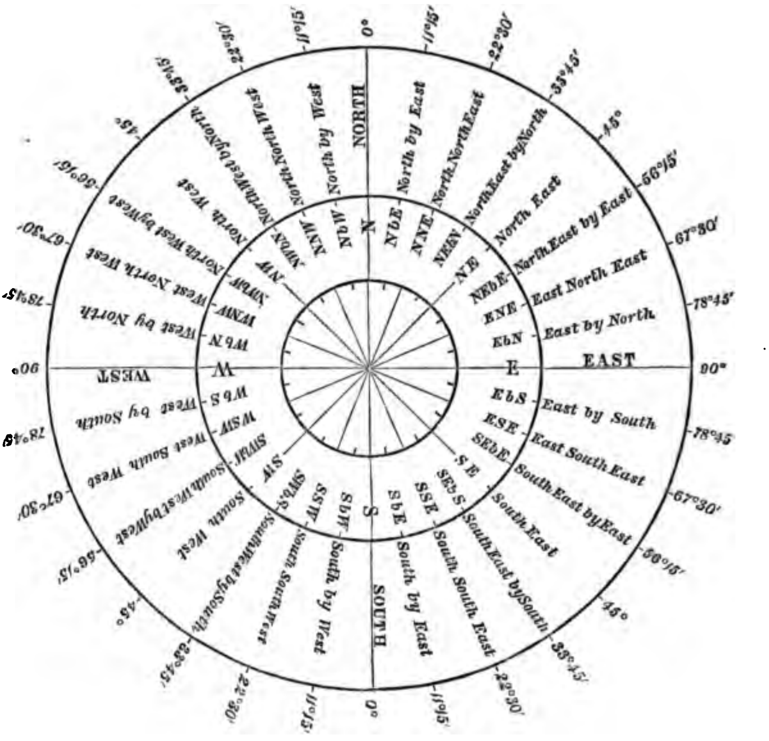
As already noticed, the meridian from which longitude is reckoned is a matter of choice. Both French and English, for example, are satisfied of the utility of the equator to measure longitudes *upon*; but they do not agree in using the same point of it to measure *from*. That Charles II. chose to build an observatory upon a hill close to Greenwich does not seem to the French reason enough to date longitude from the meridian of that hill; and we, in our turn, care as little for the meridian of that part of Paris in which Louis XIV. built an observatory for the French. But since astronomers, geographers, and travellers, of either nation, are perpetually obliged to refer to books written by those of the other, there is no problem of more common occurrence than turning longitudes reckoned from Paris into those reckoned from Greenwich, and *vice versâ*. Now Paris observatory is $9^{m}\ 21\frac{1}{2}^{s}$ east of Greenwich in longitude, or 2° 20′ 22½″. All places west, then, of Greenwich, are 2° 20′ 22½″

more west of Paris; all places east of Greenwich, but west of Paris, are east of Greenwich by as much as $2^{\circ}\ 20'\ 22\frac{1}{2}''$ exceeds the longitude which they have west of Paris; all places east of Paris are $2^{\circ}\ 20'\ 22\frac{1}{2}''$ more east of Greenwich. Or, it being now the custom to measure longitudes in time, $9^{m}\ 21\frac{1}{2}^{s}$ would be used. Thus St. Helena, $22^{m}\ 50^{s}$ west of Greenwich, is $32^{m}\ 11\frac{1}{2}^{s}$ west of Paris; and Prague, $57^{m}\ 42^{s}$ east of Greenwich, is $48^{m}\ 20\frac{1}{2}^{s}$ east of Paris.

The points of the compass may next be considered. We have already defined the North, South, East, and West. Two persons, at different points of the globe, looking north, that is, each looking to his own north, are not looking in the same direction, as they would be if the earth were an extended plane. Every point of the globe has its own north, south, east, and west, as will be easily illustrated by cutting out a number of such little compass cards as the adjoining, and laying them on different points of the globe, with the line SN directed along the meridian of the place, E. being towards the east. Seamen and travellers use names for the intermediate directions, as follows: Half-way between north and east, is North-East (NE); and similarly are explained South-East, South-West, and North-West (SE, SW, NW). Again, half-way between North and North-East is North-North-East (NNE.); and thus are explained East-North-East, East-South-East, South-South-East, South-South-West, West-South-West, West-North-West, North-North-West (ENE, ESE, SSE, SSW, WSW, WNW, NNW). Thus sixteen distinct directions are described; but a subdivision of each, giving 32 in all, still takes place. The new and final subdivisions are described each by the simplest of the two adjacent directions, and the cardinal direction in which that last direction is left. Thus North-East *by* North means the direction next to North-East in going towards the North, and comes between NE and NNE. By the same rule, North-East by North might be called North North East *by* East, but the former is the more simple. The angle of revolution from one point to the next is of course the 32nd part of 360°, or $11\frac{1}{4}^{\circ}$, and it is sometimes customary to insert fractions of a point, as follows, NNE $\frac{1}{4}$ E means a quarter of a point eastward from NNE. Each of the 32 primary directions is called a point of the compass, and thence



the interval between them, or the angle from point to point, is also called a point.



Through any place let a number of great circles be drawn, so that each begins in the direction of one of the points of the compass at that place. These great circles are easily made on the globe as follows. Elevate the pole for the latitude of the place, clamp the flexible arc at that latitude, and bring the place to the brazen meridian. Then turn the flexible arc until its 0° is right opposite to either of the points of the compass on the wooden horizon, and the edge of the flexible arc points out the circle (or a quarter of it) which sets off from the place in the direction of that point of the compass. For instance, it is required to know what places would be visited by a traveller who sets off from London in direction ESE and travels on a great circle of the earth. Elevate the pole 51½°, bring London to the meridian, clamp the flexible arc at 51½°, and, pushing the flexible arc between the globe and the wooden horizon, bring its edge opposite to ESE; then the flexible arc will go down France, Germany, Austria, Turkey, will touch the coast of Asia Minor, cross the South of Palestine, and skirt the western coast of Arabia. But it is not all this time cutting through the spots it passes in an ESE. direction: it will be almost obvious to the eye that the angles it makes with the several meridians change from meridian to meridian. To see this better, observe that it passes nearly through Jaffa, and Kosair in Arabia: let us then ask in what direction, *with respect to the points of the compass at Jaffa,* must a person set out from that place that he may travel in a great circle to Kosair. The latitude of Jaffa is 32°; depress the pole from 51½° to 32°, bring Jaffa to the meridian, clamp the flexible arc at 32°, and turn it till it passes through Kosair. It will then be seen that the primitive direction of outset from Jaffa, as shown by the arc on the woodon horizon, is not ESE but SE.

The magnetic needle is said, in common language, to point to the north, and, roughly speaking, this is correct. But nothing is better known than that this needle seldom points exactly to the north, but usually some degrees from it, one way or the other. This variation of the magnet is different in different places, and its law is laid down in a general way, by the dotted lines drawn over the sea on the globe. Look at the Cape de Verd Islands: through them passes a line which lower down is described as the line of 15° variation west. All along this line, the *magnetic north* (direction of the needle) is 15° west of the true meridian: and here and there are arrows cutting one another headed N (north) and MN (magnetic north), the MN arrow pointing out 15° west of the N arrow. A ship on this line wanting to sail any particular course, steers 15° wrong by her compass to be right by the meridian. In sailing from the Cape de Verd Islands to Pernambuco, the variation changes rapidly, and the lines of 10° and 5° are passed before the port is arrived at: in coasting from Pernambuco to Rio Janeiro, the line of no variation is passed, and the variation becomes east. With this explanation we may drop further notice of the magnetic variation, and speak of true points of the compass.

It appears that a ship, which sails over a great circle, must be continually altering the *course*, or point of the compass by which she is steered. But the plan in sailing is, to let the course alone as long as may be, or to sail on one course. On what sort of curve, then, does a ship sail which keeps one course? If the course be due north or due south, on a great circle, a meridian; if due east, or due west, on a small circle, a parallel to the equator; if not on one of the cardinal points, on a curve which is no circle, great or small.

The whole globe being sea, suppose a ship to set off from the equator, always steering north-east. Suppose the sphere mathematically exact, and the ship a mathematical point. It is certain this point could never *reach the pole:* for at the instant of reaching the pole, it would be steering *north;* whereas by supposition, it is always steering north-east. It is as certain that it must be always approaching the pole, for nothing higher than an east or west course could keep its distance from the pole unshortened. It always approaches, then, but never reaches the pole: after proceeding upwards obliquely from the equator, through a long arc not very unlike a part of a great circle, it begins to turn, and winds round the pole, getting closer and closer at every fold. To find what course a ship ought to steer, so as by keeping that course uniformly, to start from one given point, and arrive at another, is not a problem for the globe, at least not without tedious and troublesome processes. The student who is interested in this subject should procure a *Mercator's Chart,* which is a chart on which the sphere is distorted in such a manner that the spirals just mentioned are converted into straight lines, and the courses required can be found by a common straight ruler. Such a chart is more useful to the seaman than globes and all other maps put together; but we cannot here attempt to explain it further.

When it is said that one place bears, say south-east of another, it is generally meant in the nautical sense; that is, the course which must be constantly steered from one place to arrive at the other is south-east. But persons in general would imagine that the one place would lie on a great circle drawn so as to set out south-east from the other: thus Kosair would be said to bear ESE from London and SE from Jaffa, as in the preceding problem. It would be easy to distinguish between the two: let the bearing found in Mercator's chart be called the *nautical* bearing, and that of the great circle joining the two the *circular* bearing; thus the circular bearing of Kosair from Jaffa is south-east. When we see in old books this paradox—"If A be east of B, for that very reason B is not west of A, unless both places be on the equator," it is this circular bearing which is alluded to. If, to reach B on a great circle from A, that great circle must set out east, then to reach A on a great circle from B, though it must be on the same great circle as before, this circle does not set out west from B, unless A and B be both on the equator.

The circular bearing may be found more accurately by having recourse not merely to the points of the compass on the wooden horizon, but to the graduated circle on the rim, in a manner which hardly needs description.

It is obvious that a degree of longitude on one of the parallels to the equator is not so long as the degree on the equator: the degree being the 360th part of its circle, and the circles diminishing as we approach the pole. To find in miles the length of a degree of longitude in any latitude, take a bit of thread (some books recommend a pair of compasses, but it is difficult to use these without damaging the globe) and take the length included between two of the engraved meridians, which are 15° apart everywhere. Measure off this distance on the equator, and see how many degrees it there answers to. Then the degree of longitude in the required latitude is such a fraction of 69 miles as the number of the degrees on the equator is of 15°. The flexible arc may also be used, which, for 15°, will coincide nearly enough with the parallel. Thus, to find the length of a degree of longitude in 50° of latitude (north or south, it is the same thing), lay down the flexible arc as near as it will go to the arc of 15° of the parallel, included between two engraved meridians at 50° of latitude. It will be seen that the arc does not entirely coincide with the parallel, but the difference will be slight, and a little more than 9½°, about 9⅝°, of the flexible arc (the degrees of which are degrees of the equator) will go on the 15° of parallel. Now when 15 gives 9⅝, 120 gives 77, by the rule of three. Multiply 69 by 77, and divide by 120, which gives 44⅛ miles for the degree of longitude. But a more accurate and equally easy mode is by the following use of the table of versed sines in the appendix. Subtract the versed sine of the latitude from 100,000, multiply by 69, and divide by 100,000. Opposite to 50° we find 35721, which subtracted from 100,000 gives 64279: this multiplied by 69 gives 4435251, and this divided by 100,000 gives 44 miles, 35 hundredths of a mile, very near to 44⅓, as taken from the globe.

Seamen measure by what are called *nautical miles*, 60 of which make a degree of latitude, or a degree of longitude at the equator; and three nautical miles make a *sea league*. Accordingly the sea league is 3·45 land or statute miles, or *three* miles, *four* tenths, *five* hundreths, which is easily remembered.

CHAPTER IV.

Connexion of the celestial and terrestrial globe—The diurnal rotation and its consequences.

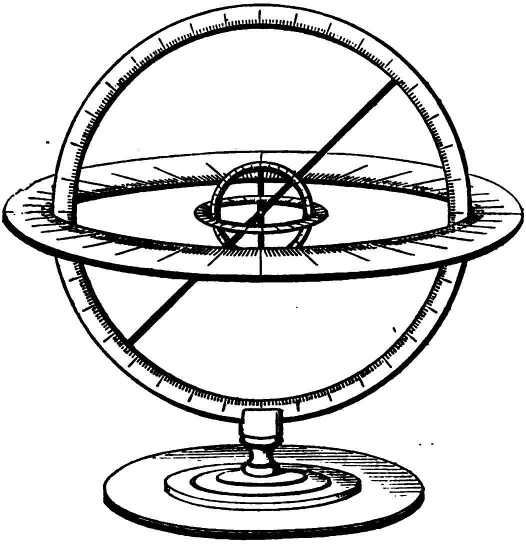
THE reasons why all celestial appearances may be safely and truly supposed to take place upon an enormous sphere are given in pages 18-20. This sphere must have so immense a magnitude that the earth must be but as a grain of sand compared to it. The astronomer, in his calculations, does not always allow even this grain of sand: he supposes the earth to be a mere point at the centre of the celestial sphere, without any magnitude at all. This supposition may entail considerable error with respect to the moon, and some with respect to the sun and planets: but it is only for the moon that the error is of any consequence to a person who uses the globes, and it is easily corrected.

It is not altogether true that the heavens appear like half of a globe over our heads. They seem rather to resemble a vault, the roof of which is nearly flat, but curving towards the walls, which themselves curve outwards. However this may be, the sphere is still the proper representation for our purpose; and a star on the vault must be imagined to be projected or shot towards its place on the sphere by a line drawn from the eye, which is always the centre of the sphere.

A person who stands outside the celestial globe must learn to consider himself as occupying an undistinguishable place at its centre. The terrestrial globe, with its brazen meridian and other appurtenances, must be at this centre, reduced to invisibility. When wanted for separate use, this last globe may expand its dimensions, but when compared with the celestial globe, it must be the atom, the grain of sand, at the centre. It must be so small that human beings on all parts of it see the same forms in the several groups of stars: the only difference being that, as they stand in different directions, different points of the heavens come directly above their heads. No degree of smallness can affect direction, and if the earth itself were no bigger than a common marble, with all its inhabitants in proportion, all celestial phenomena would remain as at present. The spectator must remember to diminish himself accordingly: if his globe be made a grain of sand, he is only as an atom, compared with the grain of sand, on its surface. In reality he is as a giant, bigger than millions of stars put together, situated on the outside of the celestial sphere, speculating upon the appearances which the dots on the sphere will present to the invisible atoms situated on the hardly visible grain at its centre. The celestial globe may be imagined to be transparent, and the following question then arises. If the imaginary figures in which the stars are grouped, or constellations, be drawn on the transparent globe, the spectator on the outside and on the inside will see them alike in all respects except one: that which seems to be the right hand to one spectator will be the left hand to the other. This will be evident on looking at any drawing of a human figure through the paper on which it is drawn. Hence a star must be described as in one hand or in the other, on one side or on the other, according to the spectator for whom it is described. Such ambiguity might be avoided by not painting the figures on the globe, but sticking on it thin flexible statues with backs and fronts, so that no two persons, wherever placed, could describe different hands as being the right hand. But then a necessity of the same kind would occur in another form: a star which is on the back to a spectator on the outside, would be on the front to one in the inside, and *vice versâ*. This is not of any consequence as to modern works, in which description by parts of constellations has long ceased: but in reading older works it is necessary to be known.

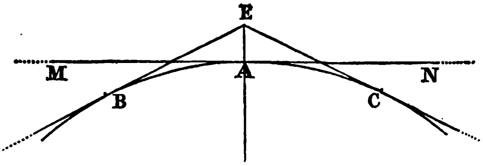
The practice of the ancients was to suppose that the internal spectator sees the fronts, and the external spectator the backs; accordingly in globes they showed the backs of the figures, and in maps the fronts. A map of the stars is always an inside view of the heavens. The moderns have adopted various plans: maps have been constructed fronting inwards, with the backs of figures presented to look like globes; globes have been made with figures fronting outwards, to look like maps; and the most modern globes have a sort of mixture of right and wrong. The way of setting any figure right is however very simple: Ptolemy, whose catalogue, or edition of Hipparchus's catalogue, was used until the modern methods came in, made himself the giant outside the universe, and took an outside view of figures fronting inwards. Accordingly, whenever the figure in the globes we are describing is seen sideways, or from behind, the stars will always agree with Ptolemy's description: thus his bright star in the right shoulder of Orion is on the right shoulder of Orion in our globes; and the stars in the left legs of the Great Bear are in his left legs on our globes. But when the figure is seen fronting us, as Auriga, then Ptolemy's descriptions are reversed; the stars which he describes as in the right arm are on the left arm in our globes, and *vice versâ.*

The preceding circumstance fortunately makes no confusion as to east and west: for when the atom on the interior earth looks towards the north pole, he turns his back upon the giant outside, so that both have the same side of the celestial globe on their right.



The axis of the celestial globe is the axis of the terrestrial globe lengthened (see the diagram, in which the internal or terrestrial globe is of course immensely magnified), and the celestial globe must be imagined capable of revolving without the terrestrial, to represent the diurnal motion of the heavens. The two brazen meridians are in the same plane, that is, the edge of a ruler placed on the inner one is always on the other: the wooden horizons are also in the same plane. The horizons are fixed; the meridians can be elevated or depressed, but both together, so that one being elevated or depressed through any angle, the other is elevated or depressed through the same. The point in the heavens which is directly above any point of the earth, called the *zenith* of that point, is found by drawing a line from the centre to the celestial sphere through the point: and this line is the *vertical* line at the place, and is the line the direction of which the plumb-line takes, and is perpendicular to the level plane of that place, or the plane of still water.

Hitherto the horizon has not been mentioned except as a convenient name for a certain wooden circle; it must now be explained astronomically. If the eye of the spectator were at A, on the surface of a sphere generated by the revolution of BAC, it would see nothing below the plane generated by the revolution of MAN; the sphere would hide all below that plane.



If the eye were raised to E, it would see nothing inside the cone generated by the revolution of CEB, except the part of the surface of the sphere generated by CAB. In either case the bounding surface, line, or plane, has been called by writers on the subject the horizon of the senses, the *sensible* horizon; but most particularly the plane when the eye is supposed at the surface. A plane parallel to this plane, drawn through the centre, has been called the *rational* horizon, being in fact no other than the plane in which the wooden horizon lies, the place being made the uppermost point of the globe. In the minute terrestrial globe which is placed inside the celestial globe, it is clear enough that the rational and sensible horizon cannot be distinguished from one another, so near are they together: the nearer parallel planes approach one another, the more nearly are they the same plane. But the horizons, rational or sensible, of two different places, may differ to any extent in direction, however small the sphere may be.

In the terrestrial globe, in which the wooden *horizon* is only the name of a convenient appendage to the stand, the spectator may imagine himself anywhere on the globe, and need not fix the globe in any one position rather than another, so far as forming a complete idea of the meaning of the instrument is concerned. But in the celestial globe this wooden horizon is a reality, absolutely essential to forming a proper notion of almost every problem. It is the continuation of the plane which is the level plane to the atom of a spectator at the centre: or at least only sinks below it by the semi-diameter of the barely perceptible grain of sand which we have supposed to represent the earth. Hence the internal globe, the one that is magnified in the diagram, must have its pole and axis elevated so that the spectator's point may be uppermost, that is, must be elevated by the latitude of the place. But the celestial globe, which is always on the same axis, must be as much elevated, and then the zenith of the spectator's place will be the uppermost point of the celestial globe. Accordingly, before using the celestial globe, elevate the pole, by means of the *upper* graduations, by as many degrees as there are in the latitude of the place. This is the explanation of the common assertion of astronomical books that *the altitude of the pole of the heavens is equal to the latitude of the place of observation.*

The equator of the heavens answers to the equator of the earth, and is in the same plane with it: the ends of the celestial axis are the poles of the celestial equator, as the ends of the terrestrial axis are those of the terrestrial equator. The north and south points of the horizon are those through which the axis may be made to pass, the east and west points are on the spectator's right and left as he looks towards the north. The spectator's meridian is represented by the eastern rim of the brazen meridian: it contains in succession, the north point of the horizon, the north pole, the zenith, the highest point of the equator, and the south point of the horizon: it also contains the highest point of every parallel to the equator. The equator always meets the horizon in its east and west points. The part of the heavens which is visible is that which is represented by the half of the globe which is above the spectator's horizon, and rules will be given for so placing the globe as to point out that part of the heavens for any given day and hour. When the globe is so placed that the upper half represents that visible to the spectator, the lower half represents the part which is visible at his antipodes. One turn of the globe represents all that takes place in a day—or rather a very little more than a turn, as hereafter explained. The reader must be sure that he has a clear perception of all these things before he attempts to proceed further: and in particular he must frequently remember to remove himself from the outside to his proper place and dimensions in the inside. *How must I place the globe?* must always be accompanied by *Where must I place myself?* until a perception of the answer to the second question becomes a matter of habit.

For further exercise let the following assertions be considered:—(1.) At the north pole of the earth the north pole of the heavens is the zenith, and the equator is the horizon. Nothing rises or sets above or below the plane of the horizon, on account of the diurnal motion of the heavens; that is, nothing but the sun, moon, and planets, which have motions of their own besides the motion of the heavens, can ever come and go. One half of the heavens is never seen. All the fixed stars describe parallels to the horizon, no one being higher or lower at one time than at another. (2.) When the spectator descends a little from the pole of the earth towards the equator, the pole of the heavens falls off as much from the zenith: half the equator rises above the horizon, and half falls below it. Only a small portion of the heavens yet rises and sets above and below the horizon; namely, as much each way from the equator as the pole has fallen off from the zenith: thus a man at 5° from the pole of the earth would only see rising and setting throughout 5° north and 5° south of the equator. There is but little obliquity in the motion of the fixed stars. The greater part of the hemisphere on the spectator's side of the equator is always seen, and as much of the hemisphere on the other side is never seen. (3.) As the spectator increases his distance from the pole, all these phenomena are increased in intensity. The pole falls down farther from the zenith, the equator rises higher, still always passing through the east and west points. A larger portion of the heavens rises and sets; the always visible portion about the north pole, and the never visible portion about the south pole, become less and less. The obliquity of the stars' motion increases, that is, they rise from the horizon more nearly perpendicular than before. (4.) When the traveller has arrived on the earth's equator, the pole has fallen quite into the horizon, and the equator passes through the zenith; the south pole begins to be visible on the south point of the horizon. No part of the heavens is either always visible or always invisible; and half of every parallel to the equator is seen above the horizon. The stars emerge perpendicularly from the horizon, and fall perpendicularly upon it again. (5.) Passing the equator towards the south pole, all the phenomena re-appear in an inverse order, the south pole of the heavens gradually rising towards the zenith. All this may be readily seen on the celestial globe, by elevating the pole for the successive latitudes of the supposed places of observation.

It is hardly necessary to say that the diurnal rotation of the heavens, which we have supposed to be familiar to the reader, takes place in the direction from east to west: that is, when a person looks towards the south, the left side of the horizon is coming into view, the right side going out. To say that stars, &c. rise *in the east* is not true, unless by the east be meant all that is east of the meridian, and by the west all that is west. Some stars rise very near the north, others very near the south; but always on the eastern side.

CHAPTER V.

The constellations—Modes of designating and cataloguing the stars, with some account of the various anomalies which have crept into use—List of the constellations—The Greek alphabet.

THE reader must now, having adjusted the globe for his own latitude, proceed to examine the manner in which the stars are represented; a subject on which some little historical account will be necessary. The shining points of light with which the heaven is filled when the sun is down and the sky clear, acquired the name of *fixed* stars (fixed with respect to each other, moving together with the whole heaven) long before the means of watching their motions were so good as to tell that a great many of them have slow motions of their own, in all manner of independent directions. This is of no consequence, for these motions are so very slow that many hundreds of years must elapse before a globe now made is rendered useless by these changes of place. Two or three other larger motions exist, which are common to all, and which will be noted in their proper places; these are still too small to affect the propriety of the term *fixed stars.*

The permanence of relative position, and the irregularity of distribution, cause many remarkable groups to be seen, which groups have from the earliest times received names; they are called constellations. Let the reader find out for himself in the heavens, if he do not know them already, Orion, the Great Bear, or Cassiopea, and he will have a pretty good idea of a constellation, or conspicuous group of stars.

Our names of constellations are mostly derived from the Greeks, and are almost altogether connected with mythological stories. It is not likely that the Greeks were the original framers of these constellations, though it may very possibly be that they received the plan from the East, and interwove stories of their own. It is not my intention to enter into the fables attached to the names of Hercules, Orion, Argo, &c.; these fables are not only uninstructive as to the use of the globes, but they have not even the property of elucidating the connexion between the astronomy and the mythology of their framers: it is but rarely that out of the various accounts (frequently half a dozen) given of the origin of each constellation, one can be selected which has any bearing on the connexion of the appearance of that constellation with the time of the year at which it begins to be clear of the rays of the sun. The astronomers took these constellations from the mythologists at their real value, namely, as commodious means of describing the stars: thus, from the time of Hipparchus and Ptolemy (B.C. 150—A.D. 150) up to that of Bayer (A.D. 1600), one star was designated as "the bright star in the right shoulder of Orion," another as "the foremost star in the right fore-leg of the Bear," and so on. Bayer, towards the end of the sixteenth century, published the first charts in which the stars were not only constellated, but distinguished in their constellations by letters. Beginning with the Greek alphabet, he put α to the star which he considered brightest, β to that which was next in brightness, and so on throughout the constellation: using the Roman letters when the Greek ones were exhausted. His successors added more letters, frequently going through both the Greek alphabet and the Roman where Bayer had only exhausted a part of the Greek, and sometimes even adding another alphabet of capital Roman letters. They also added constellations, particularly after the telescope had increased the number of visible stars: and there was at one time among observers a mania for adding new constellations, of several of which it may be said that the faintness of the stars which compose them well represents the present fame of the astronomers who named them. Most of these minor constellations are rejected in astronomical catalogues, the stars in them being considered as belonging to the most adjacent ancient constellation: but many of them still keep their places on the globes. In those we are considering, they are described in a small Roman letter, and have no boundaries marked; the broad boundary line will point out in which of the principal constellations they lie.

The next step in the mode of denoting the stars was that made by Flamsteed, who numbered the stars, not in order of brilliancy, but in that of coming on the meridian. Thus, 1 Orionis, 1 of Orion, means the first which comes on the meridian of all the stars in Orion which Flamsteed observed and recorded; 7 Leonis, 7 of the Lion, is the star of Leo which comes seventh on the meridian, of all the stars which Flamsteed noted in that constellation. As long as a star has either Bayer's letter, or Flamsteed's number, both are used indifferently and perfectly understood; nor is it expected that there will be any connexion between the letter, which refers, or was supposed to refer, to the brightness of the star, and the number, which is derived from its position. Thus, 1 Virginis happens to have ω for its letter; it is only of the sixth magnitude, though it comes early on the meridian: but α Virginis, a splendid star, is 67 Virginis in Flamsteed.

Piazzi adopted a mode of numbering, not connected with the constellation, but with the hour of right ascension (afterwards explained). The heavens being divided into 24 equal parts, by hour circles drawn through the poles, he made a consecutive numbering of all the stars in each hour, in the order in which they come on the meridian; 1 being the earliest, 2 the next, and so on. But in order further to distinguish the stars, he added the name of the constellation to each. Thus Bayer's κ in Draco, or κ Draconis, the 5 Draconis of Flamsteed, is (129) Draconis of Piazzi: not that it is the 129th star which Piazzi observed in Draco, but that it is a star of Draco, the 129th of all those which Piazzi observed in the 13th hour of right ascension. Bradley's stars are numbered in the order of his catalogue, with the same distinction of constellation: thus κ Draconis just named is [1689] Draconis, when Bradley is quoted; namely, the 1689th star of the catalogue, and in Draco. By an easily remembered alliteration, Piazzi's number is placed in parentheses ( ), and Bradley's number in brackets [ ]. Hevelius numbered the stars in each constellation, according to his appreciation of their magnitudes. Modern catalogues are numbered throughout like that of Bradley.

The celestial globe is a representation, not made directly from the heavens, but from the astronomer's catalogues: if therefore the third should be incorrect in any point, the first will be the same. Various sources of error and confusion exist in these different catalogues: attention has been lately drawn to the subject, and it appears that almost every mistake which could have been imagined, has been made in some instances. Many, indeed most, of these mistakes have been adopted by makers of globes and maps, who would not have ventured to correct Flamsteed or Piazzi, even had they had the means of doing so. In the globes which this work is intended to describe, these errors have been corrected so far as they have been stated to exist on good authority: the following description will give some idea of them; the lists are from Mr. Baily's edition of Flamsteed's catalogue.

1. The same star has been placed in two different constellations; the observer taking it on different nights, forgetting the second time that it had been observed before, and considering it, at the second observation, as apparently falling into a constellation different from that which he originally gave it to. Thus, 69 Piscium is 40 Andromedæ; 106 Piscium is 51 Ceti; 2 Arietis is 107 Piscium; 38 Arietis is 88 Ceti; 1 Eridani is 90 Ceti; 112 Tauri is 23 Aurigæ; 30 Aurigæ is 32 Camelopardi; 58 Camelopardi is 30 Lyncis; 10 Leonis is 1 Sextantis; 67 Leonis is 53 Leonis Minoris; 36 Virginis is 29 Comæ Berenices; 31 Comæ Berenices is 13 Canum Venaticorum; 10 Draconis is 87 Ursæ Majoris; 4 Libræ is 53 Hydræ; 6 Libræ is 58 Hydræ; 24 Herculis is 51 Serpentis; 28 Herculis is 11 Ophiuchi; 43 Herculis is 17 Ophiuchi; 31 Scorpii is 38 Ophiuchi; 25 Aquarii is 6 Pegasi; 27 Aquarii is 11 Pegasi; 24 Piscis Australis is 79 Aquarii. The first names are those preferred by Mr. Baily.

2. Stars have been entered which have no existence at all in the places assigned to them: such places being obtained either by writing down the observation wrongly or by error of computation. There is one remarkable exception, 34 Tauri, which was certainly seen by Flamsteed, and rightly noted, but which nevertheless does not exist as a fixed star: it was probably the planet Uranus, then undiscovered, and being for the time in the constellation Taurus. These stars, which owe their existence to wrong reading of an instrument, or a slip of the pen, are 50, 56, and 108 Piscium; 24 and 74 Ceti; 29 and 41 Cassiopeæ; 19 Persei; 13 Camelopardi; 3, 8, 15, 34, 82, 124, and 138 Tauri; 31 Eridani; 12, 26, and 65 Orionis; 17, 29, 50, 72, and 73 Geminorum; 26, 56, 73, and 74 Cancri; 8 and 36 Hydræ; 12 Leonis Minoris; 25, 28, and 38 Leonis; 18, 19, and 45 Virginis; 19 and 34 Comæ Berenices; 1 Libræ; 33, 52, and 54 Serpentis; 6, 46, 48, and 59 Ophiuchi; 71, 80, and 81 Herculis; 8 Sagittarii; 56, 62, and 70 Draconis; 33, 34, 40, and 43 Aquilæ; 5 and 38 Cygni.

3. Stars have been correctly observed, as far[*] as can be known, but are not now visible. They are 28 *Arietis,* 100 Tauri, 27 Camelopardi, 21 *Geminorum,* 7 Ursæ Majoris, 28 *Sextantis,* 91 *Virginis,* 55 Herculis, 65 Ophiuchi, 80 Aquarii, 3 Cassiopeæ.

4. There are stars in the catalogue to which no original observations are found, and which do not exist in the heavens: how they got into the catalogue cannot even be conjectured. These are 76 Orionis, 12 Canis Minoris, 17 Navis, 22, 23, 24, and 52 Virginis, 22 Canum Venaticorum, 42 Serpentis, 11 Vulpeculæ.

5. Mr. Argelander, of Bonn, in his *Uranometria Nova,* recently published at Berlin, states in effect that there are in the parts of the heavens visible at Bonn, as many as 40 stars *visible to the naked eye* which have never been entered in any catalogue at all. The list of these is as follows (south declination being marked S):

Constellation.	Rt. Ascension.	Declination.
Cassiopea	21° 56′	57° 9′
Perseus	24 53	47 6
Cetus	28 49	16 6S
Orion	78 15	8 16
Orion	84 31	9 28
Gemini	89 50	24 15
Monoceros	94 11	11 17
Canis Major	99 46	20 37S
Lynx	111 13	46 31
Argo	112 19	14 8S
Monoceros	121 27	5 18S
Ursa Major	133 34	59 59
Argo	137 55	23 49S
Ursa Major	165 28	69 9
Leo	175 41	13 10
Canes Venatici	186 51	37 16
Draco	225 26	55 10
Draco	228 51	52 30
Draco	230 0	63 55
Draco	235 57	55 52
Draco	241° 35′	58° 15′
Draco	250 53	55 42
Hercules	258 11	49 52
Ophiuchus	260 32	0 55S
Draco	260 54	60 11
Ophiuchus	264 32	5 46
Sagittarius	272 18	18 40S
Ophiuchus	272 51	7 11
Hercules	273 56	17 45
Ophiuchus	275 3	6 29
Sagittarius	281 35	16 34S
Sagittarius	284 8	15 54S
Cygnus	297 41	59 17
Capricornus	305 32	15 35S
Cygnus	306 22	55 32
Cepheus	318 42	57 57
Cepheus	319 7	60 5
Cygnus	321 38	47 44
Cepheus	331 41	59 58
Cepheus	331 51	62 30

Mr. Argelander has made this catalogue to consist entirely of stars seen by himself with the naked eye; and the preceding list contains those against which he has not been able to place any designation from a preceding catalogue. I am not at present able to say whether, in the short interval since the publication of Mr. Argelander's work, any other astronomers have verified the assertion relative to the existence and visibility of these stars. It is perfectly possible, and not unlikely, that the varieties of purpose and method under which the existing catalogues have been made may have allowed as many as 40 visible stars to escape classification: it is also perfectly possible that Mr. Argelander's eye may be more than usually good. It is pretty certain that no two persons giving a register of the heavens visible to the naked eye would have the same number of stars to set down.

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[*] Mr. Baily had access to Flamsteed's original entries, and was thus able to trace most of the non-existing stars (all in the second list) to mistakes of one or another kind. Those in the third list may arise from error which he was not able to trace (those in Italics are suspected of having arisen from reading the wrong minute of the time of transit), or from planets, or may be variable stars which have long periods of brightness and faintness, or finally, may have been stars which have since been *destroyed.*

6. But the greatest source of confusion in globes is not in the mere appearance of non-existing stars, or non-appearance of existing stars; but in the manner in which the boundaries of the constellations have been drawn. Part of the mischief has arisen from the double names of several of the stars: the boundary-makers have sometimes carried one constellation into the middle of the very figure of another, to take in a double-named star under its wrong name. The same practice, to a still greater degree, has originated from the inadvertent reference of a good many stars to the wrong constellations. A person, for instance, observing a number of stars in one evening, all of one constellation except one or two, might easily enter one of these last, inadvertently, as belonging to the constellation which immediately preceding observations would suggest to his mind. This of course would not make him put down the wrong right ascension or declination; so that, when his stars come to be arranged in a catalogue (in the formation of which there is no occasion to have recourse to a map or globe, which would detect the incongruity) he will appear to have carried the boundaries of a constellation much beyond usual limits, so as to take in one or more isolated stars, very distant from the principal group of the constellation. By such a mistake, Flamsteed has set down a star as being 13 in Argo, which is really in Canis Minor, with a whole constellation between it and Argo. In the globes here described, the reasonable boundaries are in broad dotted lines; but where the old boundaries differ from them a faint dotted line shows the track of the old boundaries. Look at Canis Minor, and in one corner will be seen a star marked 13 in

Argo, being the star misnamed by Flamsteed. The faint line shows that it was thought necessary by globe-makers to carry a part of Argo through the body of Monoceros, in order to take in this stray star. In the globes before us, all that is palpably absurd in boundaries has been rejected, but the name of no star has been changed. Whenever, by restoration of a rational boundary, a star has been shut out of what is usually called its constellation, the name of the constellation has been printed in italics near the excluded star, as in the instance before us, in which '13 *in Argo Navis*' is attached to a star within the boundary of Canis Minor. I believe the following to be a correct list of the outlying stars, which have a name from one constellation, and a position in another: not including those already mentioned, which have names in two constellations.

13 Of Argo is in Canis Minor; 33, 34, 35 of Camelopardus are in Auriga; 50, 52, 54 of Camelopardus are in Lynx; 54, 64, 65 of Cetus are in Aries; 28 of Coma Berenices is in Virgo; 1, 2, 3, 4, 5, 6, 8, 9, 10, 17, 18, 19, 20, 22, 23, 25, 26, 28, 29 of Crater are in Hydra; 3 of Cygnus is in Vulpecula; 77, 78, 79, 80 of Draco are in Cepheus; 3, 66 of Hercules are in Ophiuchus; 1, 2 of Hydra are in Monoceros; 1, 2, 3, 4, 5 of Leo Minor are in Lynx; 6, 41, 49 of Leo Minor are in Leo; 25 of Leo Minor is in Ursa Major; 37, 39, and 44 of Lynx are in Ursa Major; 31 of Monoceros is in Hydra; 32, 33, 34 of Ophiuchus are in Hercules; 23 of Pisces is in Pegasus; 1 of Sagitta is in Vulpecula; 2 of Sagittarius is in Ophiuchus; 24, 25, 28, 30, 31, 32, 33 of Scorpius are in Ophiuchus; 48 of Serpens is in Hercules; 10, 11 of Sextans are in Leo; 16 of Triangulum is in Aries; 10, 19 of Ursa Major are in Lynx; 46 of Ursa Major is in Leo Minor; 101 of Virgo is in Bootes.

The proximate cause of all this confusion, so far as regards the nomenclature of stars, is to be found in the fact, that for more than a century and a half, a map or a globe has been only of secondary use to the astronomer. Catalogues arranged in order of right ascension are more convenient than either; and in these catalogues each star is one thing, unconnected with any other. Thus, though two stars may be called α and β Tauri, the occurrence of the word Taurus in both is no assistance in finding either. By means of the right ascension and declination entered in the catalogue, either star is found in the heavens without any help from the word Taurus. If therefore a few stars should be wrongly named, it is no very great inconvenience. At a time like the present, when catalogues are undergoing extensive revision, their defects of course excite notice: and but for such revision, astronomers themselves would be hardly aware of the number and extent of the anomalies. To this it must be added that it is hardly sixty years since boundaries were made to the constellations: the older makers of charts and globes contented themselves with putting each star into its constellation, without undertaking to say how far every way from the main group the constellation should extend.

It will be seen on the globes, by comparing the broad-lined (or newly-proposed) boundaries with the faint-lined (or old ones), that not only are some of Flamsteed's stars made to lie out of their constellations, which have been noted, but also some of Hevelius, Piazzi, &c., which have *not* been noted. The truth is, that with regard to all the more recent catalogues, only that of Hevelius has numberings connected with the constellations; the others are numbered through the catalogue, with names only from the constellations. And since Flamsteed took in nearly all the stars which are visible to the naked eye, it is sufficient for the ordinary user of the globe to be put in possession of the means of avoiding confusion with respect to any of his stars.

The magnitudes of the stars are derived, by mere unassisted judgment, from their apparent brilliancies. Certain very bright ones are said to be of the *first* magnitude: not that these are all equally bright, but that each one of them is supposed to be more brilliant than any of those which are not of the first magnitude. A large number of stars, no one of which is of the first magnitude, but which are supposed to be severally more brilliant than any of the remaining ones, are said to be of the *second* magnitude; and so on. Opinions vary much about the magnitudes of stars; all admit that there is little to choose between the faintest of any one magnitude and the brightest of the next order beneath: custom has fixed the magnitudes in a manner which has an uncertain quantity of truth about it, and, near the boundaries of each class, a certain quantity of confusion.

The globe may now be described as follows:—

1. All the stars are brought up to the year 1850. The meaning of this will be seen when *precession* is explained.

2. All the stars have been entered which the catalogues from whence they are taken state to be of the ninth or any brighter magnitude: and the star is always entered as having the magnitude which is given to it in the catalogue from which it is taken. Thus if a star of Hevelius, of the sixth magnitude, should appear brighter than one of Flamsteed's of the fifth, as may possibly happen, all that can be said is that the globe-maker does not examine the heavens, but the catalogues; and must describe Hevelius's star after Hevelius, and Flamsteed's after Flamsteed.

3. The catalogues which have been employed are Flamsteed's, Piazzi's, Hevelius's, and Mayer's, for what is called the northern hemisphere, that is, for the heavens visible as low as the southern parts of Europe, in which is a great part of the southern hemisphere; and Lacaille's and Johnson's for the remainder of the southern hemisphere which is not visible in any part of Europe. The double stars are marked from W. Herschel and Struve.

4. Flamsteed's numbers are taken from Mr. Baily's edition of the British Catalogue; and Mr. Baily has been imitated in the rejection of all the letters added by Bayer's successors; so that these globes have only the letters which are in Bayer's maps.

The faint patches of light called nebulæ* are not inserted. They are not visible to the naked eye, except only a very few, and those rarely. Any one who desires to watch them must have a good telescope, and some means of guiding it to any point in the heavens, and will certainly have catalogues. The globe is already crowded enough, without the insertion of many hundreds of little spots which are never to be seen. But it may be objected that many of the stars that *are* on the globes are invisible to the naked eye. This is true: but then it is to be remembered that these stars, invisible as they are, frequently become points of reference, even to those who do not see them. A star-gazer announces in the daily papers that he has found a comet in Ophiuchus, near xviii. 169 of Piazzi; he is announcing it to his fellow lovers of the same pursuit, and forgets the world at large. A person with a globe on which such small stars are not put down is unable to tell where he may take his chance of seeing the comet:

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* Mr. Malby informs me that he is about to publish a 36-inch globe, in which the *nebulæ* will appear, and which only awaits the publication of Sir John Herschel's observations in the Southern Hemisphere, without the results of which a globe containing double stars and nebulæ will soon be incomplete.

another, who has Piazzi's stars marked, can thus find out its place in the heavens, by means of a star which, though he cannot see it, has thus served as the medium of communication between him and the comet-finder. But nebulæ are not points of reference.

I subjoin a list of all constellations of the least importance, with nominative and genitive cases and accented syllables, for the benefit of those whose Latin is gone, or has never come: also the forms and sounds of the letters of the Greek alphabet. Stars are generally described by the genitive case; θ Virginis, θ *of Virgo,* 10 Argûs, 10 *of Argo,* are instances. The constellations are put down in the order of right ascension, from the Astronomical Society's catalogue: that is, in the order in which their several first stars appear. The proper names are not translated.

Cetus, Ceti, *Whale.*
Hydrus, Hydri, *Water-snake.*
Ursa Minor, Ursæ Minóris, *Lesser Bear.*
Erídanus, Erídani.
A'ries, A'rietis, *Ram.*
Triángulum, Triánguli, *Triangle.*
Pérseus, Pérsei.
Fornax, Fornácis, *Furnace.*
Horológium, Horológii, *Clock.*
Taurus, Tauri, *Bull.*
Camélopárdus, Camélopárdi, *Camel-leopard.*
Retículum, Retículi, *Network.*
Dorádo, Dorádûs, *Sword-fish.*
Cælum Scalptóris, Cæli Scalptóris, *Graver's Tool.*
Orión, Oriónis.
Auríga, Aurígæ, *Charioteer.*
Lépus, Léporis, *Hare.*
Colúmba, Colúmbæ, *Dove.*
Gémini, Geminórum, *Twins.*
Monóceros, Monocerótis, *Unicorn.*
Lynx, Lyncis, *Lynx.*
Canis Major, Canis Majóris, *Greater Dog.*
{Argo, Argûs,
{Navis, Navis, *Ship.*
Equúleus Pictóris, Equúlei Pictóris, *Painter's little Horse (or Easel).*
Piscis Volans, Piscis Volántis, *Flying Fish.*

Canis Minor, Canis Minóris, *Lesser Dog.*
Cancer, Cancri, *Crab.*
Ursa Major, Ursæ Majóris, *Greater Bear.*
Hydra,* Hydræ, *Hydra.*
Chamæ'leon, Chamæleóntis, *Chamæleon.*
Pixis Naútica, Píxidis Naúticæ, *Compass.*
Leo, Leónis, *Lion.*
Leo Minor, Leónis Minóris, *Lesser Lion.*
Sextans, Sextántis, *Sextant.*
A'ntlia Pneumática, A'ntliæ Pneumáticæ, *Air-pump.*
Crater, Cratéris, *Cup.*
Centaúrus, Centaúri, *Centaur.*
Virgo, Vírginis, *Virgin.*
Coma Bereníces, Comæ Berenices, *Berenice's Locks.*
Crux, Crúcis, *Cross.*
Corvus, Corvi, *Crow.*
Musca, Muscæ, *Fly.*
Canes Venátici, Canum Venaticórum, *Hounds.*
Bo-ótes, Bo-ótis or Bo-óti, *Herdsman.*
Solitárius, Solitárii, *Hermit.*
Lupus, Lupi, *Wolf.*
Apûs, A'podis, *Without feet* (*Bird of Paradise*).
Círcinus, Círcini, *Compasses.*
Libra, Libræ, *Balance.*
Serpens, Serpéntis, *Serpent.*
Triángulum Austràle, Triánguli Austrális, *Southern Triangle.*
Coróna Boreàlis, Corónæ Boreális, *Northern Crown.*
Scórpius, Scórpii, *Scorpion.*
Hércules, Hérculis.
Ophiúchus, Ophiúchi, *Serpent-holder.*
Serpentárius, Serpentárii, *do. do.*
Norma, Normæ, *Rule.*
Ara, Aræ, *Altar.*
Sagittárius, Sagittárii, *Archer.*
Pavo, Pavónis, *Peacock.*
Telescópium, Telescópii, *Telescope.*
Taurus Poniatowski, Tauri Poniatowski, *Poniatowski's Bull.*

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* The feminine of Hydrus, which is also a constellation; but as *Hydra* has become an English word, this translation may be preserved for distinction.

Cly′peum Sobieski, Cly′pei Sobieski, *Sobieski's Shield.*
Lyra, Lyræ, *Lyre.*
A′quila, A′quilæ, *Eagle.*
Coróna Austrális, Corónæ Austrális, *Southern Crown.*
Vulpécula, Vulpéculæ, *Fox.*
Cygnus, Cygni, *Swan.*
Sagítta, Sagíttæ, *Arrow.*
Capricórnus, Capricórni, *Goat-horned.*
Delphínus, Delphíni, *Dolphin.*
Cepheus, Cephei.
Indus, Indi, *Indian.*
Aquárius, Aquárii, *Waterman.*
Microscópium, Microscópii, *Microscope.*
Octans, Octántis, *Octant.*
Equúleus, Equúlei, *Little Horse.*
Piscis Austrális, Piscis Australis, *Southern Fish.*
Pégasus, Pégasi.
Grus, Grúis, *Crane.*
Lacérta, Lacértæ, *Lizard.*
Tucánus, Tucáni, *Toucan.*
Pisces, Píscium, *Fishes.*
Andrómeda, Andrómedæ.
Apparátus Sculptóris, Apparátus Sculptóris, *Sculptor's Workshop.*
Cassiopéa, Cassiopéæ.
Phœnix, Phœnícis, *Phœnix.*
Draco, Dracónis, *Dragon.*

The letters of the Greek alphabet are as follow :—

Α α	a	alpha	Ν ν	n	nu
Β β ϐ	b	bēta	Ξ ξ	x	xi
Γ γ ʃ	g	gamma	Ο ο	ŏ	ŏmīcron
Δ δ	d	delta	Π π ϖ	p	pi
Ε ε	ĕ	ĕpsīlon	Ρ ρ	r	ro
Ζ ζ ζ	z	zēta	Σ σ ς	s	sigma
Η η	ē	hēta	Τ τ ꞇ	t	tau
Θ θ ϑ	th	thēta	Υ υ	u	upsīlon
Ι ι	i	iōta	Φ φ	ph	phi
Κ κ	k	kappa	Χ χ	ch	chi
Λ λ	l	lambda	Ψ ψ	ps	psi
Μ μ	m	mu	Ω ω	ō	ōmĕga.

CHAPTER VI.

Relative position of the celestial and terrestrial globe—Right ascension and declination—The sidereal day—Altitude and azimuth.

Adjust the celestial globe as follows. Place the north pole towards the north by means of the compass underneath; or, which will do just as well for our present purpose, let the direction towards which the north pole points be considered as the north. Elevate the pole (as in page 43), by means of the upper graduation, to the latitude of the place in which you are: then the part of the sphere which is above the wooden horizon at one time contains all that part of the heavens which you can see at one time: and, turn the globe as you may, the elevation remaining unaltered, the part above the wooden horizon always contains a portion of the heavens which is all visible at some one time in every twenty-four hours.

For instance, elevate the globe to the latitude of London, $51\frac{1}{2}$°, and bring Sirius, the bright star in Canis Major, to the eastern side of the horizon. We have thus a complete command of the general state of the heavens when Sirius is rising. The bright star in Canis Minor has attained some elevation, Orion's belt more, and Aldebaran (α Tauri) still more. The head of Aries is on the meridian, that of Cetus is coming on, and also those of Medusa and Perseus. The head of Camelopardus has just passed the meridian at its lower transit, and the seven stars of the Great Bear had their lower transit some time ago. The head of Bootes, which never sets, is approaching its lower transit; Hercules, Aquila, and Aquarius, are going to set; Cygnus is long past the meridian. All this takes place every day at the rising of Sirius, whether the sunlight will prevent us from seeing it or not. It would be useless to multiply examples of this very simple case: the globe is elevated for the latitude of the place, and when it is desired to see how the heavens stand when a given star is rising, culminating (that is, passing the meridian), or setting, put that star on the eastern horizon, on the meridian, or on the western horizon, accordingly, and then proceed to examine the parts of the globe which are above the horizon.

When a star is on the meridian of London, to what other places is it also on the meridian? Answer, to all those places which have the same longitude as London, or which come on the brazen meridian of the terrestrial globe with London.

When a star passes over our heads in London, at what other places of the earth does it also pass over the heads of the inhabitants? Answer. At all those places which have the same terrestrial latitude as London.

When a star rises or sets at London, where else is it also rising or setting? This question shall be answered as soon as it can be told over what spot of the earth the star is at the moment, or to what place it is in the zenith. When a star rises or sets at London, it must be in the zenith to some place in the great circle of which London is one of the poles. Bring London to the eastern horizon, taking a chance elevation of the globe: and note what place is then on the highest point of the globe (call it A). Then, when the inhabitants of A see it over their heads, all those on the eastern horizon (and at London among the rest) are just losing it, or seeing it set; all those on the western horizon (and at the antipodes of London among the rest) are just gaining it, or seeing it rise. Observe here that the horizon is not used as an horizon, but merely as a circle to which the highest and lowest points of the globe are poles: also, that any other place may be used instead of London, and the sun, moon, or a planet, instead of the star.

To distribute the heavens over the earth, or, knowing what star is on the meridian at Greenwich, to find what stars are on the meridian, and particularly what stars are vertical, at other places. Take both globes; elevate both globes for the latitude of Greenwich: bring Greenwich to the brazen meridian on the terrestrial globe; and the star which is named as on the meridian at Greenwich, on the celestial globe. Then all the stars are vertical to the places which are similarly placed on the terrestrial globe: or if the surfaces of the two globes could be made to coincide, and the brazen meridians also, every star would be made to fall upon the place to which it is vertical. Turn either globe east or west through a certain number of degrees on its equator, and do the same with the other globe, and still the same thing continues: the globes are matched in the same way as before. If an apparatus were contrived which would turn both round in the same direction, and in the same time, then every *star* which is on the celestial brazen meridian at any one instant would be on the meridian to all the *places* which are on the terrestrial brazen meridian at the same instant.

For instance, let the moment chosen at which to distribute be that at which α Andromedæ is on the meridian at Greenwich. Both globes being elevated 51½°, bring α Andromedæ and Greenwich to the brazen meridians of their several globes. Then it will be seen merely by comparing positions with the unassisted eye, that Cassiopea is vertical over the northern parts of Europe, Lyra over the United States, Taurus over Hindostan, Andromeda over the Mediterranean, &c. But to know more precisely what place any particular star is over will require the star to be brought on the meridian, and the terrestrial globe to be turned through an angle equal to that which the celestial globe was turned through. Thus the star 57 Andromedæ, about 41° from the equator, will come on the meridian when the globe is turned from east to west through about 28½°. Turn the terrestrial globe westwards about 28½°, and then look at 41° of latitude, and it will be found that 57 Andromedæ is very nearly over Constantinople when α Andromedæ is on the meridian at Greenwich.

We must now proceed to define the modes in which the positions of the stars are given. The equator is the principal circle employed: it is the circle of progression and regression (page 7) most commonly used. The zero of progression upon it is the *vernal equinox*, the point at which the sun's centre crosses the equator when ascending into the northern hemisphere. Progression, measured from this vernal equinox, on the equator, in the direction from west to east, is called *right ascension* :* and regression is not used. All secondaries to the equator are called *hour-circles ;* or rather each half of a secondary to the equator is an hour *semi*-circle, the two halves of the same secondary belonging, as will be seen, to different hours. This answers exactly to a similar remark made on the meridian in page 25: in fact, a meridian on the earth always answers to an hour-circle in the heavens. At any one moment, all points of one and the same hour-circle are zeniths to the points of one and the same meridian: but let any time elapse, and, by the diurnal motion of the heavens, the hour-circle which was everywhere vertical to any specified meridian, has become vertical to some other meridian on the west, while another hour-circle has become vertical to the first-named meridian. Every star is on one hour-circle, and on one only: unless it be at one of the poles of the equator (or one of *the* poles), and then it is on all hour-circles. The arc of its hour-circle which comes between the star and the equator, the shortest arc which can be drawn from the star to the equator, (the *departure* of page 7,) is called the *declination* of the star, and is said to be north or south, according as the star is on the north or south side of the equator.

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* So called to distinguish it from *oblique ascension*, a term so completely out of use that it is not worth explaining.

A point in the heavens is completely known when its right ascension and declination are known. For example, is there or is there not a star in 256° of right ascension and 36° of north declination. There is attached to the celestial globe a brazen hour-circle, the counterpart of the brazen meridian on the terrestrial globe. Bring 256° on the equator to the brazen hour-circle, then all the stars having 256° of right ascension are under the brazen hour-circle. Look up the northern side of the brazen hour-circle, from the equator, and under 36° *exactly* there is no star, but very close is 3 Herculis. Again, it is required to find the right ascension and declination of 35 Tauri. Find the star, and bring it to the brazen hour-circle. Then on the equator, at the brazen hour-circle, we read 58°; on the brazen hour-circle, over the star, 12¼°. Consequently the right ascension of 35 Tauri is 58°, and its declination 12¼° north.

Right ascension and declination are thus connected with terrestrial longitude and latitude. The diurnal motion of a star of (say) 26° north *declination* is fully described by saying that it passes over the heads of all spots on the earth which are in 26° north *latitude*. A person who lives anywhere in 26° north latitude has over his head, once in every day, *every* star of 26° north declination. Thus declination and latitude are perfect counterparts of each other. Right ascension and longitude are also connected in this way: two stars which differ in their *right ascensions* by (say) 10°, are at every instant on the meridian at places which differ by 10° of longitude: the eastern star to the eastern place, and the western star to the western. When the vernal equinox (which has 0° of right ascension) is on the meridian of Greenwich (which to Englishmen has 0° of longitude), then every star is on the meridian to places which have as much of *east* longitude as the star has of right ascension. Remember that right ascension is measured *all round* from west to east, while longitude is measured half-way east and half-way west. Thus when the vernal equinox is on the meridian of Greenwich, places 10° east of Greenwich in longitude have, on their common meridian, all the stars which have 10° of right ascension: but places 10° west of Greenwich (or 350° east) have on *their* common meridian all the stars which have 350° of right ascension.

The distance of two stars may be measured with the flexible arc, or calculated from the tables, just as the distance of two places was measured or calculated in pages 30-32. In the calculation, for latitudes use declinations, for *differences or sums* of longitude use *differences* of right ascension.

The revolution of the heavens being made from east to west, and right ascension being measured from west to east, the stars come on the meridian in the order of right ascension; that is, a star of right ascension 61° comes on the meridian just after one of right ascension 60°. The diurnal revolution is of course equal to the interval between two successive transits of any one star over the meridian. It is always of the same duration, *but it is not what is commonly called the day, or* 24 *hours by the clock.* The common or civil day is a few minutes longer, as will be afterwards shown: the actual revolution of the heavens is an *astronomer's day* under the name of the *sidereal* day. The astronomer always makes it begin when the vernal equinox is on his own meridian, he divides it into twenty-four *sidereal* hours (each a little shorter than the hour of the common clock) of 60 *sidereal* minutes of 60 *sidereal* seconds each, and he measures it by a *sidereal* clock (with a pendulum a very little shorter than that of the common clock). He rejects the subdivision into two periods of 12 hours each, and speaks of 15 o'clock, or 16 o'clock, under the phrase 15 *hours* or 16 *hours,* meaning 15 or 16 hours from the commencement of the sidereal day, from the time when the vernal equinox was last on the meridian. Neither does he name the *sidereal* days Sunday, Monday, &c., but when he uses those names, he refers to the common days. Thus Monday, May 6, 1844, 10^{h} 20^{m} sidereal time at Greenwich, is in the day which all Europe calls May 6, 1844, at $10^h\ 20^m$ by the sidereal clock.

Measure right ascension in time (page 6), and the right ascension of a star shows the sidereal time at which that star is on the meridian. Thus, a star having 56° of right ascension, or $3^h\ 44^m$ (at 15° to an hour), the clock shows, or ought to show, $3^h\ 44^m$ of sidereal time when that star is on the meridian. And at two different places, sidereal clocks, properly regulated, always differ by the difference of their longitudes turned into time, the eastern place having the faster clock. For instance, Madras is about 77° 56′ east of Paris in longitude, which turned into time is about $5^h\ 12^m$, the time by which the sidereal clock at Madras is faster than that at Paris. Accordingly, when it is 22^h by the sidereal clock at Paris, it is $3^h\ 12^m$ of the next sidereal day at Madras.

A large number of problems may now be illustrated on the globe, and with a certain degree of accuracy, performed. The answers, when in time, are in sidereal time: accordingly, they cannot be reduced to ordinary, or civil, time, till we have considered the motion of the sun, which it has of its own, over and above (or rather in diminution of) what it gets from the diurnal motion of the heavens.

The *hour angle* of a star is the angle which its hour circle makes with the meridian of the place (represented by the brazen hour-circle when the globe is properly elevated). This hour angle is nothing when the star is on the meridian, and is an hour of *angular measure* for every *sidereal hour* to or from the time of the transit, being eastward before transit and westward after it.

What is the position of the heavens at Greenwich $4^h\ 30^m$ before, and the same time after, Aldebaran (α Tauri) has passed the meridian? In the first case the hour angle of Aldebaran is $4^h\ 30^m$ east; in the second, $4^h\ 30^m$ west. Elevate the globe for the latitude of Greenwich, and bring Aldebaran on the meridian: the right ascension appears to be $4^h\ 27^m$. Turn the globe $4^h\ 30^m$ westward, so that $8^h\ 57^m$ is upon the meridian, and the globe represents the heavens when the hour angle of Aldebaran is $4^h\ 30^m$ westward; turn the globe $4^h\ 30^m$ eastward, so that $23^h\ 57^m$ is on the meridian, and we have the same for the same hour angle eastward. In a rougher way proceed as follows. When you have brought Aldebaran to the meridian, turn the brazen parallel (which will turn without the globe) until 12 on the parallel is also on the meridian. Then you may turn the globe eastward or westward any number of hours by turning the brazen parallel (globe and all) through that number of hours. But it is better (if the utmost exactness which a globe will give is to be obtained) that the equator should be used, and not the brazen parallel.

When the horizon is made the circle of progression and regression, then distance of arc measured on the horizon from its north or south point is called north or south *azimuth*; but when measured from the east or west point, it is called east or west amplitude. The secondaries of the horizon, which all pass through the zenith, are called vertical circles, and the *altitude* of a star is the arc of its vertical circle which lies between it and the horizon. Hence azimuth or amplitude (according as we take our zero of progression) answer to progression or regression; and altitude answers to departure. Thus the place of a star may be settled, for a given moment, by its azimuth and altitude, or by its amplitude and altitude, just as well as by its right ascension and declination, or a place on the earth by its latitude and longitude. But there is this important distinction to be drawn: right ascension and declination are measured upon circles which share the diurnal motion of the heavens, so that while the stars move, the circles of reference move with them. But azimuth and altitude are measured upon circles which are as fixed as the spectator; so that both azimuth and altitude vary from moment to moment in the same star. For example, it would be absurd, having a star whose right ascension is known, to ask what time it is, sidereal, at a given place; because a star has the same right ascension, or right ascensions of imperceptible difference, at all times of the day, and for all places. But it would be perfectly reasonable to ask the time of the sidereal day at which a given star has an altitude of 20° at a given place before coming to the meridian: because there are but two moments at which the given star has the required altitude at a given place, one on the east and one on the west of the meridian. We therefore propose a problem of the preceding kind, being content with sidereal time for the present, till we can change it into time by the common clock; that is, till we are able to compare the motion of a star with that of the sun. These problems are of two classes, as to their character on the globe: those in which the latitude of the place is given, and those in which it is sought. In the latter the globe, instead of being elevated at the beginning, has to be elevated or depressed during the process of solution; and in some of them nothing but repeated trials can succeed, unless circles be drawn with compasses on the globe, to the injury of its surface. To prepare the globe for problems of a given latitude, elevate the globe for the latitude, clamp the flexible arc at the latitude on the lower graduations (page 36): then the flexible arc can be turned so as to represent any vertical circle at the given place.

The flexible arc, when thus fixed, and its end inserted between the horizon and the globe, ought to have its 0° at the horizon all the way round. But, supposing this to be the case when it leaves the maker's hands, it by no means follows that it will remain so. Wood must warp more or less, and brass must be flexible; accordingly the possessor of a globe must not be disappointed if he find that he must have recourse to those corrections which even the best astronomical instruments demand, after hundreds of pounds have been spent in trying to secure accuracy at the outset. It may be reasonably expected that the divisions on the flexible arc shall coincide with those on the equator and brazen hour-circle without sensible error: but it is difficult to suppose that the bevelled edge by which the position for clamping is decided should be very accurately in a line with the pivot of rotation of the flexible arc. To try this, clamp very loosely, and bring the flexible arc just under the brazen hour-circle, or with its divisions just emerging. Move it carefully up and down until 0° on the meridian just coincides with say 50° on the flexible arc: clamp it in this position, taking care that it does not slip. Then the bevelled edge ought to show as if it had been clamped at 40° (the rest of 90°); but if, as will usually be the case, it should fall a little short of 40°, the quantity by which it falls short should be remembered, or scratched with a pin on the flexible arc itself, and always taken as a correction. If, for instance, when 0° is on 50° of the flexible arc, the bevelled edge should mark 39½°, it is a direction, in setting the flexible arc, always to clamp the edge at half a degree less than the latitude required, in order to bring the pivot of rotation exactly under that latitude.

Given the latitude of the place, and the altitude of a known star, required the hour of the sidereal day. For instance, Regulus, or α Leonis, is at 50° of altitude on the east of the horizon, the latitude being 40°. Elevate the globe for the latitude of 40°: clamp the flexible arc over 40° in the manner above described, find Regulus, and also 50° on the flexible arc, and insert the lower end of the flexible arc within the wooden horizon, so that the arc may wrap over the globe. Move the globe and arc separately, with care, until Regulus is on 50° of the arc, and east of the horizon. This will require a little practice and patience; a moderately good eye will soon learn to put the star near its required altitude before bringing the arc on the globe. Then read what degree of the equator is on the meridian, which it will be seen is $7^h\ 47\frac{1}{2}^m$, and this is the sidereal time required. To find the hour-angle, take $7^h\ 47\frac{1}{2}^m$ from 10^h, the right ascension of the star, and there remains $2^h\ 12\frac{1}{2}^m$ for the hour-angle, and also for the sidereal time which will elapse before the star is on the meridian. If the altitude had been 50° on the western side of the meridian, the hour-angle would have been the same towards the west, and the sidereal time would have answered to the star's right ascension, increased by $2^h\ 12\frac{1}{2}^m$, or $12^h\ 12\frac{1}{2}^m$. The globe in this instance gives only about half a minute of error.

It is always allowable to add or subtract a whole revolution, 360° or 24^h as the case may be: and this is sometimes requisite. Suppose for example that the sidereal time is $22^h\ 18^m$, and the star's right ascension $2^h\ 4^m$. Now $22^h\ 18^m$ cannot be taken from $2^h\ 4^m$: add 24^h to the latter, and $22^h\ 18^m$ taken from $26^h\ 4^m$ is $3^h\ 46^m$, the star's hour-angle.

CHAPTER VII.

The sun's motion—Ecliptic and colures—Solar day—Combined circular motions—Reckoning of time—Mean solar day—Sidereal and tropical years—Celestial latitude and longitude—Signs of the zodiac—Precession of the equinoxes—Kalendar—Irregularity of the sun's motion—Comparison of sidereal and solar time—Equation of time—Mode of setting the globe for any time—Defects of the horizon of a globe.

THE sun has a motion of its own, besides that which it has in common with the stars. But the peculiar motion is from west to east, not from east to west. It moves upon a great circle of the sphere, called the ecliptic, which is drawn upon both the globes. This circle cuts the equator at two places, called *equinoxes.* The ecliptic has a motion of its own which will be afterwards discussed: this motion is so slow as not to become sensible on any globe for many years.

The poles of the ecliptic are at this time 23° 27½′ distant from those of the equator: and this is the angle which the equator makes with the ecliptic, and the greatest declination which any point on the ecliptic can have. The points of the ecliptic which have the greatest declination, north and south, are called *solstices:* each solstice is half-way between the two equinoxes, and each equinox is half-way between the two solstices. The hour-circle which passes through the two equinoxes is called the *equinoctial colure;* and that which passes through the poles of the ecliptic and the solstices is called the *solsticial colure.* A point on the equinoctial colure must have either 0° or 180° of right ascension, and one on the solsticial colure must have either 90° or 270° of right ascension. The parallels to the equator, north and south, which pass through the poles of the ecliptic, are called the *arctic* and *antarctic* circles: those which pass through the solstices are called the tropic of Cancer and the tropic of Capricorn. All this is common to both globes: but on the terrestrial globe the ecliptic may have its equinoxes laid down anywhere, provided only that its poles keep the proper distance from the poles of the earth; while on the celestial globe the equinoxes must be properly laid down among the stars.

The interval between two transits of the sun over the meridian is called a *solar day*. It is longer than the sidereal day (page 64): for if the sun move slowly eastward, and if it be on the meridian with a star A to-day, then to-morrow, when A comes on the meridian, the sun will be a little to the eastward, or not yet on the meridian: that is, the solar day is not quite completed in a sidereal day. But though every solar day be longer than a sidereal day, the solar days are not all equal to one another: the motion of the sun in right ascension not being uniform, or its daily increase of right ascension not being the same in every day, the excess of the solar over the sidereal day is slightly variable.

The astronomer's real solar day begins when the sun's centre is on the meridian, or at *real noon:* 1^h (not one *o'clock*, for no clock shows *real* solar time) arrives when the hour-angle of the sun's centre is 15° west, 2^h when the same hour-angle is 30°, and so on. And 12^h arrives, when the sun is on the meridian opposite to the spectator, or at *real midnight:* 13^h, when its hour-angle is 165° eastward, and so on until 23^h, at which the hour-angle is 15° eastward. Or thus, imagine a set of hour-circles, the first 0^h, on the meridian, and numbered westward 1^h, 2^h, &c., but not partaking the diurnal motion of the heavens. It is then 5^h of real solar time when the sun is at the hour-circle marked 5^h. The hour is longer than the sidereal hour, in the same manner as the day is longer than the sidereal day, because the sun is moving slowly eastward. Neither are the solar hours strictly equal *to one another*, for the sun's motion is not *exactly* the same even from hour to hour. The sun-dial is a contrivance to show the sun's hour angle, or the *real solar time:* the common clock shows the average of the real solar hours *all the year round*, or the *mean* solar hours. This common clock is regulated by a fictitious sun, called the *mean* sun, which is almost as often mentioned by astronomers as the sun itself, so that the latter must sometimes be called the *true* sun, for fear of mistake. The mean sun is made to move *regularly round the equator* in the same time as that in which the true sun moves *irregularly round the ecliptic.* The true sun and mean sun are never actually together, for when they have the same right ascension, they have not the same declination: the reasons which make such an arrangement convenient cannot be explained to a beginner.

It is *mean noon* when the mean sun is on the meridian; it is one o'clock (the clock *does* show the time we are now speaking of) when the hour-angle is 15° westward, and so on. The difference between the hour-angle of the true sun and the mean sun, turned into time, is called the *equation of time*, and it expresses the difference between the time shown by the sun-dial and that shown by the clock. This equation of time is marked on the wooden horizon, and will presently be further described.

The astronomer's mean solar day begins when the mean sun is on the meridian, or at mean noon, and ends at the next noon. Hence all that we call the forenoon of one day belongs to the preceding day in astronomical language. Thus 11 o'clock in the morning on Monday, May the 14th, is, with the astronomer, 23^h of Sunday, May the 13th. But 2 o'clock in the afternoon is the same day of the week and month with both.

When a globe revolves, and a point moves *upon the globe*, besides revolving with the globe, it is exactly the same thing as if the point revolved at a quicker or slower rate than the globe. If the point make half a revolution upon the globe, at the same time and in the same direction as the globe makes half a revolution upon its axis, it will have made a whole revolution by the time the globe has made half a one: but if the point make its half revolution in the contrary direction to that of the globe, it will not revolve at all, its own revolution destroying the effect of that on the globe. Every motion of the sun from west to east, is, so far as the sun is concerned, a slackening of the diurnal motion from east to west: so that, by the time the sun has made its whole annual revolution from west to east, it has lost a day, that is, in the reckoning. The number of its real revolutions is one less than the number of the real revolutions of a star in the same time. So that when a body moves *upon a globe, and also with the globe*, its phenomena are accelerated by its moving in the same direction as the globe, and retarded by its moving in the opposite direction.

But suppose a person moves upon a fixed globe, such as we suppose the earth to be, and views a moving globe, such as our heavens. It is now clear that if he move the same way as the heavens, he retards all diurnal phenomena: the motion of the heavens, to him, is the excess of the celestial revolution over his own, caused by his travelling on the fixed globe; if he could move fast enough, he might keep the sun on his meridian, or, more properly, change meridians as fast as the sun, and have it always noon. And his day's journey westward, though not much, is something towards retarding the sunset, or lengthening the day; while his night's journey lengthens the night. All this is reversed, if he move eastward. Again, in further illustration (though this involves the very thing to be illustrated) when he moves westward, he comes among those (page 65) whose watches are slower than his own, and the sun will set and rise by their watches, not by his: the contrary if he travel eastward.

Let a traveller set out at noon from Greenwich, and reach the opposite side of the globe, also at noon: when it is noon on that opposite side, it is midnight at Greenwich. The same absolute time, therefore, is from a noon to a midnight to those who stay behind, or half a day more than an exact number of days: while to the traveller it is the interval between two noons, or an exact number of days. If then, according to the traveller's reckoning, 200 days have elapsed from the noon at which he left Greenwich, to that of his arrival on the opposite side, those who stay behind would call it either 199½ or 200½ days. Suppose the traveller to go *eastward;* he then goes round on the earth in a direction opposite to that in which the heavens go round the earth, and, as has just been said, shortens his day. That is, he counts time during his journey by shorter days than those whom he left behind, or his 200 days are their 199½ days. But had a second traveller gone *westward,* and employed 200 days of *his* reckoning (a different one from that of the first) he would have reckoned in longer days, and his 200 days would have been 200½ days of those whom he left behind. He would therefore reach the opposite side a day after the one who went eastward. But each traveller setting out from Greenwich at the same time, and reckoning 200 days on the voyage, would give the same name to the day of his own arrival: if the one who went east arrived on his own Tuesday, the one who went west, and came in the day after, would equally arrive on *his own* Tuesday, or the other's Wednesday. And so it would be whether they took the same or different numbers of reckoned days, and whether the number was 200 or any other. And if, instead of two travellers going each half-way round, one only had gone all the way round, that one would be a day before the observatory at Greenwich, on his return, if he went eastward, and a day behind, if he went westward.

The actual revolution of the sun is performed in 365 days, 6 hours, 9 minutes *of mean solar time* (it is unnecessary here to be more exact); that is, so much common clock time elapses between two moments at which the sun has the same right ascension with Aldebaran, for instance. But in *sidereal* days, this is $366^d\ 6^h\ 9^m$, since one revolution of the heavens is, in that time, counteracted by the sun's contrary revolution. It is very close to the truth to say that 731 mean solar days make 733 sidereal days. And 24^h sidereal is $23^h\ 56^m\ 4^s$ mean solar, while 24^h mean solar is $24^h\ 3^m\ 56\frac{1}{2}^s$ sidereal. A star then, which to day is on the meridian with the mean sun (or at 12 *o'clock*) is to-morrow on the meridian at $3^m\ 56^s$ before twelve. This is the daily acceleration of the fixed stars, the daily (mean solar day) gain of the observatory sidereal clock upon the common clock in mean solar time. And in so small a quantity as $3^m\ 56^s$ it will not be worth our while to distinguish mean solar from sidereal time. For questions on the globe, when wanted, convert an interval of mean solar time into sidereal by adding one minute for every six hours, and of sidereal into mean solar by subtracting one minute for every six hours.

This year of $365^d\ 6^h\ 9^m$ is no more the year of common life, or the civil year, than the sidereal day is the civil day. Those who should use the sidereal day, the actual revolution of the heavens, to regulate their domestic affairs, must either alter their dinner hours (by their clock) every now and then, or would dine at noon in one part of the year, and at midnight in another. And a civil year, consisting of an actual revolution of the sun round the heavens, would in time bring the harvest into February, and the snow into July. In consequence of the slow backward motion of the equinoxes, the sun meets the equator again, or comes to the autumnal equinox, in a little less than half an actual revolution round the heavens. The precession of the equinoxes, so called, really means this—that the heavens are very slowly changing the axis round which they spin, and the poles of the equator; the extremities of that axis revolving on the heavens round the poles of the ecliptic in about 26,000 years, from east to west. Take the globe, and make the north pole of the ecliptic its highest point, by elevating it 66½°, and then bring the pole of the ecliptic on the brazen hour-circle; that is, bring the ecliptic to the wooden horizon. Imagine the poles of the equator to revolve from east to west, carrying the equator, the hour-circles, and parallels, with them, the stars and ecliptic remaining fixed. It is now clear that the intersections of the equator and ecliptic, or the equinoxes, will also revolve slowly from east to west, completing their revolution in the same time as that of the poles. But the sun revolves from west to east, and will therefore meet the vernal equinox, which is going in a contrary direction, sooner than it would have done if the latter had remained fixed. Or the time between two coincidences of the sun with the vernal equinox, which is called the *tropical* year, and is the common or civil year, is shorter than the actual revolution of the sun round the heavens. It is in fact 365 days 5 hours 49 minutes. The retrograde motion of the equinoxes is about a degree in 72 years.

The reason why the tropical year is chosen is that it is the period in which the phenomena of the seasons are repeated, and after which they recommence. The state of the weather depends mainly upon the quantity of heat which the place receives from the sun in a day. This depends partly on the length of the day, partly on the altitude which the sun attains. Both increase or diminish together: the longer the day, the greater the altitude of the sun at any given hour, and the contrary.

When the ecliptic is made a circle of progression and regression (page 6), the vernal equinox is chosen as the zero of progression. Progression is called *longitude*, and regression is not used, longitude being reckoned from west to east all round the ecliptic. And the departure from the ecliptic, measured on a secondary to that circle, is called *latitude*, north or south, according to the pole to which it is directed.

To find the longitude and latitude of a star, bring the pole of the ecliptic to the brazen hour-circle, and clamp the flexible arc over it: let it be the north or south pole of the ecliptic, according as the latitude is north or south. Turn the flexible arc till it comes over the star, that is, until the graduated edge is just on the centre of the star. Then the point of the ecliptic on which the graduated edge falls shows the longitude of the star, and the point of the flexible arc on which the star falls shows the latitude. Elevate the globe so as to get at the star most conveniently, but take care that the solsticial colure is all on the brazen hour-circle.

It used to be the practice, and is still among globe-makers,* to divide the ecliptic into 12 signs of 30 degrees each, answering to twelve constellations, with the following names and signs: the parts adjacent to the ecliptic being called the *zodiac.*

Aries	♈	from	0°	to	30°		Libra	♎	from	180°	—	210°
Taurus	♉	—	30°	—	60°		Scorpio	♏	—	210°	—	240°
Gemini	♊	—	60°	—	90°		Sagittarius	♐	—	240°	—	270°
Cancer	♋	from	90°	to	120°		Capricornus	♑	from	270°	—	300°
Leo	♌	—	120°	—	150°		Aquarius	♒	—	300°	—	330°
Virgo	♍	—	150°	—	180°		Pisces	♓	—	330°	—	360°

The reason is obvious enough. When the Greeks first established the zodiac which has descended to us (for whether they got it from the east, or invented it, it is their zodiac which we have) the equinox was in about the same longitude as the beginning of the constellation Aries. The ecliptic, as it then stood, had its circumjacent stars formed into twelve groups, with the preceding names, except only in the case of Libra. This constellation did not exist in the Greek zodiac, but the Scorpion was one constellation, and its *claws* another. There were then 12 groups, over each of which the sun travelled in about a month. All this was done when the equinoxes were supposed to be steady in the heavens: and though the precession of the equinoxes gradually carried away the first 30 degrees of the ecliptic, from the group of stars called Aries, still this first 30 degrees retained the name of Aries, the second 30 degrees of Taurus, and so on. So that the Aries of the *ecliptic* is now almost all in the *constellation* Pisces, and so on. To say that a star was in 7° 32′ of Gemini, was to say that its longitude was 7° 32′ more than 60°, or 67° 32′: such longitude would also be called 2 signs, 7 degrees, 32 minutes.

The Greek astronomy probably took its rise about B.C. 400, and the equinox is placed, in the globe we are describing, for the year 1850. In 2250 years the equinoxes have retrograded on the ecliptic about 31½°. Look forward 31½° on the ecliptic, and it will be seen that the equinox was probably nearly under the star β Arietis when the zodiac was first written about.

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* And so it should be, for nothing ought to be omitted on a globe which will embarrass the historical student.

Required the longitude and latitude of β Andromedæ. It is on the north side of the ecliptic: bring the north pole of the ecliptic on the brazen hour-circle, and clamp the flexible arc over it. Elevate the globe so as to bring β Andromedæ and the part of the ecliptic under it both well into sight above the wooden horizon, and turn the flexible arc, taking care not to move the globe, until β Andromedæ is on the graduated edge. Then on the ecliptic we read $28\frac{1}{2}$° of Aries, and $25\frac{3}{4}$° on the flexible arc. According to Ptolemy, this latitude was $25\frac{1}{3}$°, and longitude 3° 50′. The difference of latitude is no more than might be expected from the rough character both of Ptolemy's observations and of measurements on a globe: by that of longitude we may make a guess at the time when Ptolemy lived. The precession of the equinoxes alters the longitudes of all the stars, increasing them by as much as the equinox has moved backwards; and leaves the latitudes unaltered. Granting that the longitude of β Andromedæ has increased from 3° 50′ of Aries to 28° 30′ of the same, or 24° 40′, and reckoning 72 years to a degree, we are to infer that Ptolemy lived 1776 years before 1850, or A.D. 74. In truth he lived A.D. 150.

About the ecliptic it will be seen that eight degrees of latitude are carefully marked off both by parallels of latitude and secondaries of longitude: the whole forming a net-work round the ecliptic. Within this network the moon and the old planets are always seen; so that they are easily found by longitude and latitude without the assistance of the flexible arc. For instance, a planet is in longitude $165\frac{1}{2}$° and in latitude $6\frac{3}{4}$° north, what star is it near? Look out on the ecliptic for $15\frac{1}{2}$° of Virgo (♍), and count $6\frac{3}{4}$° upwards: it appears that the planet is right between 77 Leonis (77 of the *constellation* Leo) and the small star above it, but nearer to the latter.

Since the tropical year is not an exact number of days, but the civil year must be, it is clear that the civil year must not always consist of the same number of days. The tropical year is 365^d 5^h 49^m, the common year is 365 days. If every year were a common year, the mean sun (page 70; it will do for our purpose, being always nearly at the same hour-angle as the true sun) would be at the equinox 5^h 49^m later every succeeding year. The equinox would then progress about a day in four years; or the period of equal day and night would be found at all times of the year in the course of 1460 years: if June 24 be properly *midsummer*-day now, it would become *mid-winter* day in 730 years. To avoid this, the well-known expedient of leap-year is resorted to: one year out of four is made a day longer. But this overdoes the necessary correction, for the equinox in four common years does not gain 4 times 6^h, but 4 times 5^h 49^m, or 23^h 16^m. Consequently at the end of four years the equinox is 44^m earlier than at the beginning. The best plan would be to have seven periods of four years, with a leap-year in each, and then a period of *five* years, with a leap-year among them: or to add 8 days in 33 instead of 32 years. But 8 in 33 is very nearly 97 in 400, that is, the omission of three leap-years in four centuries will very nearly make the average year coincide with the actual one; the equinox will go backwards only a day in 3600 years. The plan of the omission of three leap-years in 400 years is as follows; according to the old, or Julian plan, 1700, 1800, 1900, and 2000, would all be leap-years; of these only 2000 is allowed to be so in the Gregorian plan. The last year of each century is or is not leap-year, according as the number of centuries is or is not divisible by four. Remember that A.D. 100 *ends* the first century, A.D. 1900 *ends* the nineteenth century, and so on.

The Sun moves irregularly, or rather undergoes a regular change of its rate of motion: its motion is slowest at the end of June, most rapid at the beginning of January. This motion is laid down in detail both on the wooden horizon and on the ecliptic. Look on the wooden horizon, proceed from the outer edge, pass over the figures written sideways, and there is a circle on which are marked the days of the month. and another on which are marked the degrees of the several signs. Thus over against January 15, is seen 25¼° of Capricornus, and the same is seen on the ecliptic. This means that at noon of January 15, the sun's longitude is 25¼° of Capricornus, or 295¼°. The next division answers to six in the evening, the third to midnight, and the fourth to six in the morning. Thus at midnight on the 22nd of February, the sun is at 4¼° of Pisces in the ecliptic. All this is for the *first year after leap-year*. The civil year, as we have seen, begins about six hours too soon, or six hours before a revolution of the sun (supposed to have begun with the last year) is completed. For every year then (till leap-year sets it right) the sun's longitude is less at any noon then it was at the same noon of the year before. Roughly speaking, a degree a day is the sun's motion in longitude, or a quarter of a degree for a quarter of a day. For the second year after leap-year then, diminish the longitude marked on the globe by a quarter of a degree, for the third by half a degree: but for leap-year itself increase by a quarter of a degree at and after the first of March. Thus in the third year after leap-year, on the 19th of May, at six in the evening, the sun is in 28° of Taurus. In leap-year, during January and February, diminish by three-quarters of a degree, and use the first of March for the 29th of February. Thus at noon on February 29, the sun is in 10° of Pisces.

We can now put the sun in its place at any time, with sufficient accuracy for the purpose of a globe. It remains to compare the different clocks: the mean solar (or common[*]) clock, the true solar clock, or sun-dial, and the sidereal clock (page 64). In recapitulation, any quantity of time is reduced with sufficient correctness from mean solar hours to sidereal by adding at the rate of a minute for every six hours: and from sidereal to mean solar, by subtracting at the same rate. Thus 14 hours of mean solar time may be called $14^h\ 2\frac{1}{3}^m$ of sidereal time.

The sidereal clock goes through 24 hours (called sidereal) in an actual revolution of the heavens. When it shows 0^h the vernal equinox is on the meridian, and the sidereal day begins: when it shows, say $2^h\ 10^m$, the hour-angle of the vernal equinox is $2^h\ 10^m$ (or $32\frac{1}{2}^\circ$) west, the star whose right ascension is $2^h\ 10^m$ is on the meridian, the sidereal day is $2^h\ 10^m$ old at the place in question, and is beginning to those in longitude $2^h\ 10^m$ west of the place for which the clock is made.

The sun-dial goes through 24 hours (called real solar) in the interval between two meridian transits of the sun, which moves in the *ecliptic*, and *variably*, besides moving with the heavens. When it shows 0^h, the sun's centre is on the meridian, and the solar day, with astronomers, begins: when it shows, say 21^h, the hour-angle of the sun's centre is 21^h west, or 3^h east; the star, whose right ascension is 21^h more or 3^h less than that of the sun, is on the meridian; the solar day is 21^h old, and is beginning to those in longitude 3^h east of the place for which the dial is made. The hours are not quite equal throughout the year.

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[*] Only differing from the common clock in showing 24 instead of two sets of 12 hours.

The common clock, as altered for the astronomer's use, by exhibiting all the 24 hours, goes through 24 hours (called mean solar) in the interval between two meridian transits of the fictitious or mean sun, which moves in the *equator*, and *uniformly*, besides moving with the heavens. When it shows 0^h, the centre of the mean sun is on the meridian, and the astronomer's mean solar day (which only differs from the common day in beginning at a different time—noon instead of midnight—and in substituting 24^h for two sub-divisions of 12^h each) begins. When it shows, say 5^h, the hour-angle of the mean sun's centre is 5^h west; the star, whose right ascension is 5^h more or 19^h less than that of the mean sun, is on the meridian; the astronomer's mean solar day is 5 hours old, the common day 17 hours; the astronomer's mean solar day is beginning to those in 5^h west of the place for which the clock is made, and the common day to those whose longitude is 7^h east.

The sun's mean right ascension, or the right ascension of the mean sun, is the sidereal time of the moment of mean noon : and the same of the sun's real right ascension, and real noon. It would perhaps be a good thing if the course of the *mean* sun were tracked out on the equator, in the same manner as that of the *real* sun is on the ecliptic; but the small figures printed sideways on the horizon answer the purpose. These figures represent the *equation of time* at noon, that is, the quantity by which the mean solar, or clock, time is fast or slow of the true solar, or sun-dial time; or, the hour-angle of the true sun at mean noon; or, the hour-angle of the mean sun at real noon. The figures are written as for the first year after leap-year. In the course of the 24th of December, it appears that there is a moment at which the clock is neither fast nor slow by the dial; that is, the mean and true suns are on the same hour-circle. Then the clock begins to be too fast, that is, on the succeeding days the mean sun is west of the true sun, or has less right ascension. This continues until April 15, when the two are again together; on February 10, the clock was nearly a quarter of an hour fast by the dial, or the dial as much slow by the clock. After April 15, the clock begins to be too slow, or the mean sun has more right ascension than the true one; by May 15, it is about four minutes too slow; by June 14, it is again with the dial. It is then too fast again: by the 26th of July it is upwards of six minutes too fast; by the 31st of August it is with the dial again. The clock then becomes too slow, is more than 16 minutes too slow by the 2nd of November, and is again with the dial on the 24th of December.

This is the most irregular phenomenon which we have yet had to consider. It is the combination of two distinct phenomena, each of them very regular by itself, but not exhibiting the same simplicity in their united effect. The true sun moves *variably* and in the *ecliptic*: the mean sun moves *uniformly*, and in the *equator*. If the true sun were in the equator, the irregular motion would still create an equation of time: if the mean sun moved in the ecliptic, uniformly, there would still be an equation of time. The peculiarities of the sun's motion cannot be better explained than in reference to this subject.

Look on the wooden horizon, for five days before and five days after the beginning of January: it will be seen that the sun's longitude is increased 10½° in these ten days. At this rate, the year would be only 343 days. Look at the five days preceding and following the 1st of July, and it will be found that 9½ degrees is all the motion; at which rate the year would be as much as 379 days. The inequality of the sun's motion is then evident. Put a fictitious sun in the ecliptic, let it coincide with the true sun at the *perigee* (or when it is nearest to the earth) and let it revolve in the ecliptic in the same time as the true sun. If this *ecliptic mean sun* were made the regulator of the clock, there would be an equation of time, but one of a simple character: the mean and true sun would coincide at the perigee, and at the opposite point (the *apogee*) of the orbit: but from the perigee to the apogee the true sun would be in advance of the mean sun, and from the apogee to the perigee, behind it.

Now the mean sun of the equator, already described, is made to move round the equator, exactly in the same manner as the mean sun of the ecliptic, just described, moves round the ecliptic: the two being together at the vernal equinox. That is to say, the longitude of the mean sun in the ecliptic is made equal to the right ascension of the mean sun in the equator. So that the mean sun in the equator is connected in the mind of the astronomer with the true sun in the ecliptic by another intermediate fictitious body, the mean sun in the ecliptic: the two mean suns coincide at the equinoxes, move at the same rate, and are always equally distant from the equinoxes: each moves with the average rate of the true sun, and the ecliptic mean sun coincides with the true sun, not at the equinoxes, but at the perigee and apogee, that is, on the first of January and the second of July.

The mean equatorial sun and the mean ecliptic sun are never on the same hour-circle, except at the equinoxes and solstices. The summer solstice has 90° both of longitude and right ascension, the winter solstice 270° of both. But every point in the ecliptic which follows an equinox and precedes a solstice has more longitude than right ascension, and every point which follows a solstice and precedes an equinox has more right ascension than longitude. On examining the globe, for instance, it will be found that on the ecliptic, 40° of longitude has only 37½° of right ascension: but 140° of longitude has 142½° of right ascension. Consequently, from equinox to solstice, the mean ecliptic sun is behind the equatorial sun; from solstice to equinox before it. For since the right ascension of the equatorial body is equal to the longitude of the ecliptic one, when the ecliptic sun is in right ascension 37½°, the equatorial sun is in right ascension 40°; but when the ecliptic sun has right ascension 142½°, that of the equator has 140°.

It may seem strange to attach to the sun two invisible and non-existing repetitions of himself; but if these accompaniments be useful* even to the astronomer, they are indispensable to the student. By their aid it can be shown to him that the clock and the sun-dial are together four times in the year, and four only. Let P represent the mean sun of the ecliptic, Q the mean sun of the equator, and ⊙ the true sun: the critical periods being—the *winter solstice,* December 21, when the sun has its greatest south declination; the *perigee,* January 1, when the sun is nearest to the earth; the *vernal equinox,* March 20, when he has no declination; the *summer solstice,* June 21, when he has his greatest north declination; the *apogee,* July 2, when he is farthest from the earth; the *autumnal equinox,* September 23, when he has no declination again; after which comes the *winter solstice* of the next year, and so on. And we know that P and Q have the same right ascension (on which alone hour-angles and time depend) at equinoxes and solstices; that P is behind Q from equinox to solstice, and before Q from solstice to equinox. Also that P and ⊙ are together at apogee and perigee, and that from perigee to apogee ⊙ is before P, and from apogee to perigee behind it. Also, the common clock shows the hour-angle of Q, and the sun-dial that of ⊙.

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* It is true that the astronomer generally mentions the sun's *mean* longitude, instead of the longitude of the mean sun of the ecliptic; and the sun's *mean* right ascension, instead of the right ascension of the mean sun of the equator: but this is only abbreviation.

At the winter solstice, then, the order is ⊙ (PQ), or ⊙ is the hindmost and P and Q are together; but at the perigee the order is Q (⊙P). Therefore ⊙ has passed Q in the interval, or there must have been a moment at which Q and ⊙ were on the same hour-circle, or the clock and sun-dial agreed. At the vernal equinox the order is (QP) ⊙, and at the summer solstice it is still (QP) ⊙, but in the interval ⊙ has fallen behind Q, and Q has fallen behind ⊙ again, giving two places at which the sun and dial agree. This may be made out by the reader who knows, what cannot be satisfactorily shown merely by the globe, that the greatest departure of P from Q *exceeds* the greatest departure of Q from ⊙. Thus, between the vernal equinox and summer solstice P and Q are somewhere at their greatest distance, and then, for the reason just stated, the order must be P⊙Q, for ⊙ is before P till we come to the apogee. At the vernal equinox and summer solstice, then, ⊙ is before Q, and somewhere between is behind it: there are therefore two places where they pass one another. Again, at the summer solstice the order is (PQ) ⊙, and immediately afterwards it is QP⊙, and so continues till the apogee, after which it becomes Q⊙P. At the autumnal equinox it is ⊙ (QP), for P and Q are together, but ⊙ is always behind P from apogee to perigee. Consequently Q passes ⊙ between the summer solstice and autumnal equinox, or the clock and dial are once more together. From the autumnal equinox to the winter solstice the order is always ⊙PQ, and ⊙ and Q cannot come together. Thus there are four, and only four, periods at which the sun and dial are together, in the course of the year. By similar reasoning the reader may find out when the dial is fast, and when slow, as compared with the sun, and may verify the results on the wooden horizon of the globe.

To set the celestial globe in such a manner as to represent the heavens at a given *sun-dial* time in any day of any month: Make the brazen hour-circle face north and south by means of the compass at the bottom of the stand, and elevate for the latitude of the place. Find out the day of the month on the ecliptic or horizon, and bring the place at which the sun is to the brazen hour-circle, attending to the directions in page 78. Then bring the XII on the brazen parallel to the brazen hour-circle, and turn the globe eastward for the forenoon, and westward for the afternoon, until the hour you want is on the brazen hour-circle. The globe is then in the required position. To find what stars are rising, culminating, or setting, look at the eastern horizon, brazen hour-circle, or western horizon. To find the altitude of any star, clamp the flexible arc to the highest point of the globe, as in page 68, and bring it over the star, reading the altitude required on the point of the flexible arc which touches the star. To find when a star comes on the meridian, bring it to the brazen hour-circle, and look at the hour on the brazen parallel. It would be an advantage if the brazen parallel were numbered from 0 to 24^{h} after the manner of astronomical reckoning: as it is, make an ink mark over one of the places marked XII and bring that XII to the sun at noon; there may otherwise be a mistake between an hour of the forenoon and one of the afternoon. To find when a given star rises or sets, make it rise or set, and look at the brazen parallel for the hour. In fact, having set the brazen parallel for the day, and wanting the time of any phenomenon which can be imitated on the globe, imitate that phenomenon, and then look at the hour on the brazen parallel, where it comes on the brazen hour-circle. Before showing an example we shall observe that in order to give all the exactness of which a globe is capable, we must abandon the brazen parallel and look to the equator itself. Find the sun's right ascension as in page 63, and add to the right ascension the hour of the afternoon, or subtract from the right ascension the hour of the forenoon which you want. Bring the result on the meridian, which can be done to a minute, and the globe is then in the position required.

For example, I want to know the state of the heavens at half-past ten on the evening of the 27th of June, 1844, in the latitude of Greenwich. Find the 27th of June on the ecliptic, and bring the half-point between 27 and 28 (remembering that half the astronomical 27th of June has nearly past) on the brazen hour-circle. Without disturbing the globe, bring the XII of the brazen parallel which has been marked on the hour-circle also. Then turn the globe westward until $10\frac{1}{4}$ on the brazen parallel comes on the brazen hour-circle. The heads of Draco, Hercules, and Ophiuchus are near the meridian, Antares in Scorpio passed about half an hour ago, α Lyræ will be on about midnight, and α Aquilæ at a quarter after one in the morning; Algenib in Pegasus has risen but a few minutes, &c.

The little brazen parallel at the top of the globe is a contrivance for doing the roughest problems somewhat[*] more easily, at a greater sacrifice of correctness. A little practice will enable any one to make the reckoning on the equator. Having brought the sun's place to the meridian, look at and remember the *minute* of right ascension which is on the equator, in time. Remember that each of the quarter-degrees on the equator is a minute of time. The brazen hour-circle will generally be between two printed hour-lines: move it into the next space, counting one, into the next, counting two, and so on, until the number of hours is gained: taking care to move it eastward or westward, according as a morning or afternoon hour is wanted. Bring it to the minute in the new hour that was left in the old one, and add a minute for six hours, to make the difference between sidereal and solar time. Then turn the globe as many minutes farther as the time in question is past the whole hour. For instance, to find the state of the heavens very accurately (for a globe) at half-past ten in the evening, June 27, 1844. Look in the horizon for June 27; increase the longitude there found by one quarter of a degree, because it is leap-year (page 78), and by half a degree, because nearly half the astronomical day is past, and we have $6\frac{1}{4}^{\circ}$ of Cancer for the sun's longitude: bring this on the meridian. Look at the equator, and it appears that the 27th minute of the seventh hour of right ascension is culminating. Turn the brazen hour-circle into the next interval of printed hour-circles, and say *one;* into the next, and say *two;* and so on till you say *ten;* the brazen hour-circle is then between the 16th and 17th hours. To

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[*] That is, with a little saving of the mind at the expense of the body. A person who is sitting quietly at the south side of the globe, which is the position most generally useful, will, if his mind be not active enough to count on the equator, be obliged to rise, walk round the globe, and set the brazen parallel. He will finish with an error of a quarter of an hour, perhaps: by using the equator he might have been within a minute.

27 minutes remembered, add 30^m for the half-hour. Remember again that these *minutes* of time are minutes of sidereal time, and *quarter-degrees* of the equator. Thus we come to $16^h\ 57^m$ of right ascension, which bring on the meridian for the position corresponding to half-past ten. The result will be correct within one minute. It is hardly worth while to attend to minutiæ for the simple purpose of setting the globe to look at the heavens by: but every idea which can be gained of the small corrections which astronomical practice requires will be a help in understanding the subject.

All the above relates to apparent solar time, or sun-dial time: if mean time or clock time is to be used, look on the wooden horizon for the equation of time, and correct accordingly. On the 27th of June, at half-past ten, it thus appears that the clock is nearly $2\frac{3}{4}$ minutes faster than the dial, if we look on a quarter of a day for leap year, and half a day for the time elapsed since noon. Say 3^m: consequently we must use $10^h\ 27^m$ of apparent time instead of $10^h\ 30^m$ by the clock; or turn the globe 3^m eastward from the position last obtained.

Required the apparent or sun-dial time of sunrise on the same day. Early in the morning the sun's longitude will be about $5\frac{1}{2}°$ of Cancer: bring this point of the ecliptic upon the horizon. On the brazen hour-circle will then be seen $22^h\ 8^m$ of right ascension, while, when $5\frac{1}{2}°$ of Cancer was there, $6^h\ 24^m$ was there also. Consequently $6^h\ 24^m$ being $8^h\ 16^m$ in advance of $22^h\ 8^m$, the sun's hour angle (from noon) is $8^h\ 16^m$ at rising; or it rises at $3^h\ 44^m$. Calculation gives $3^h\ 48\frac{2}{3}^m$ as the proper answer, namely, that which a perfectly correct globe ought to give, without taking into account the flexure of the rays of light caused by the atmosphere. All globes are subject to more error at the horizon than elsewhere; and unless the whole horizon and stand were of metal, this defect could hardly be remedied. Many persons imagine that instruments are to give any degree of accuracy, and will perhaps think the globes described in this work are defective. For this reason, and not for invidious comparison, I take an example out of Keith's work on the subject (edition of 1834), in which $3^h\ 52^m$ is made, by the globe, to be the time of sunrise on the 1st of June, at London: calculation gives $3^h\ 57\frac{1}{2}^m$.

To try whether the wooden horizon is very well placed, elevate the globe to 90°, by the upper divisions, and then look on the other side; 0° of the brazen hour-circle should be on the horizon. Make any elevation whatever, and read the brazen hour-circle at the north and south points of the wooden horizon; the sum of the readings should be 90°: thus, if 27½ be on one, 62½° should be on the other. If this be always true, or imperceptibly false, it is a sufficient test of the meridian being well divided, and the wooden horizon being on the same level as the centre of the sphere. Now to try whether the wooden horizon is perpendicular to the brazen hour-circle, when the preceding test is satisfied, elevate the north pole 90°, and see if the *middle line* of the equator be truly on the horizon: elevate the south pole as much, and see if the same thing take place. Lastly, see if, in turning the globe, the east and west points of the equator be always truly on the horizon.

To find how a good horizon can be obtained from the flexible arc: clamp the flexible arc over the equator, and bring the solsticial colure to the brazen hour-circle; bring the flexible arc along the equator, introducing it between the wooden horizon and the globe, and see if 0° on the flexible arc coincide with an equinox. This will be the case in a good globe; but if say ½° should coincide with the equinox, then, wherever the flexible arc may be clamped, ½° on the arc will be on the wooden horizon as it ought to be, as soon as the globe is elevated for the latitude to which the clamp is fixed.

Having thus brought the reader to the determination of the actual phenomena of the sun and stars, as presented at any one moment of the year, we shall defer further problems, and shall proceed to the description of the Nautical Almanac, from which the student is to draw many of the *data* on which problems are to be worked.

⁂ Throughout this chapter I have referred to the table of the *equation of time*, which is given on the horizon of Malby's globes, as if it were usually given on globes, which is not the case. But the common almanacs give the difference between the clock and the sun, so that no reader need be at a loss on this matter.

CHAPTER VIII.

Description of the Nautical Almanac.*

THE *Nautical Almanac* is, in its present form, a volume published at the public expense for the daily wants of the astronomer and seaman. Most almanacs contain something of astronomical prediction; next to the Nautical Almanac, the one which has most of it is known by the name of *White's Ephemeris.*

The first thing which will strike a person who opens the Nautical Almanac is the excessive minuteness of the predictions; generally to the hundredth of a second of time, and the tenth of a second of arc. The first and greater of these hardly answers to five yards at the earth's equator. Now it is not pretended that the subject is so accurately known that five yards of difference on the earth's surface can make any perceptible change in the heavens: why then is such a degree of apparent accuracy assumed? For the simple reason, that the actual state of astronomy could not otherwise receive any improvement from the comparison of observation with the predictions of theory. As far as *seconds* of time are concerned, prediction and observation almost always agree. For example, the two following columns contain, the first, predictions published in 1835; the second, the actual observations of the sidereal times of transit of the moon's western edge (or *limb*), and of certain stars, over the meridian of Greenwich Observatory (for which all the predictions of the Nautical Almanac are made) on the 15th of July, 1837.

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* Commenced in 1767, under the superintendence of Maskelyne: the new and enlarged form commenced with the almanac for 1834. It is published four years in advance, thus now (in 1845) the volumes for 1845, 1846, 1847, and 1848 are on sale. The price is five shillings, but the student who wishes to be sure of having a series, should buy it as it appears, since, by the time any year commences, the volume of that year is frequently out of print. A copy of any old number, subsequent to 1834 inclusive, will do well enough for understanding the present chapter, and may be obtained, perhaps, of a secondhand bookseller.

Object.	Predicted transit. ('Nautical Almanac,' 1837, published 1835.)	Observed transit. (At Greenwich Observatory, July 15, 1837.)
α Ophiuchi	$17^h\ 5^m\ 22^s,70$	$17^h\ 5^m\ 22^s,72$
θ Ophiuchi	$17^h\ 12^m\ 2^s,92$	$17^h\ 12^m\ 2^s,89$
Moon (western edge)	$17^h\ 33^m\ 45^s,62$	$17^h\ 33^m\ 45^s,02$
γ^2 Sagittarii	$17^h\ 55^m\ 23^s,48$	$17^h\ 55^m\ 23^s,40$
δ Sagittarii	$18^h\ 10^m\ 36^s,58$	$18^h\ 10^m\ 36^s,58$

In one instance, it appears that there was not a discordance of a single hundredth of a second (this would not happen often); with no one of the stars was there so much as ,10, or one-tenth of a second. But in the case of the moon there was just six-tenths of a second, or ,60. The motions of the moon, then, seem not quite so well known as those* of the stars, and such is the fact. But neglect fractions of seconds, and the two columns will read exactly in the same manner; theory and observation will not differ at all. If, then, it be worth while (as astronomers know it to be, were it only for the determination of longitudes) to make further investigation into the moon's motion, it is clear that nothing greater than the hundredth of a second must be neglected, in setting forth the actual result of the theory as it is, for comparison with the same as it ought to be.

The first part of the Nautical Almanac consists of principal matters arranged for the twelve months of the year; and as the matter for each month is a repetition, to a line, of the facts which were given for the preceding month, the months have each a separate paging, and any page of one month is a counterpart of the same page for every other month. Accordingly the description of one month will, so far as this part is concerned, serve for all. Let it be remembered that Greenwich Observatory is the place throughout.

PAGE I. is headed *Apparent Noon.* In astronomy the word *apparent* is used not as opposed to *real*, but as coinciding with it, and opposed to *mean*. Thus *apparent noon* means real or true noon, when the true sun, the sun which *appears*, is on the meridian, as opposed to *mean noon*, when the mean sun, the average fiction of astronomers, which does not *appear* at all, is on the meridian. The first column is the *apparent* right ascension of the sun's centre at *apparent* noon. This first word refers to the equinox from which this right ascension is measured: the *apparent* equinox is the real equinox itself, the vernal point in which the very orbit of the sun for the time being cuts the equator. It is opposed to the *mean* equinox, as follows:—The orbit of the sun is very slowly and perpetually shifting its position, in such a manner that, among other changes, the equinox moves slowly, *but not regularly*, backwards, or from east to west (page 74). An equinox is made to move, with the same average motion as the real equinox, but uniformly; and this is the *mean* equinox. Apparent right ascension is measured from the apparent or true equinox; when otherwise, it is stated as measured from the *mean* equinox. As a general rule, right ascension, simply mentioned, means apparent right ascension: to the user of a globe, it is indifferent which is used, as the difference of the measurements never amounts to three seconds. The apparent declination is also given, meaning the declination measured from the equator, the position of which is subject to no changes, though the point of it from which right ascension is measured does change. Some one great circle and its poles must be taken as fixed (page 13), and the equator and its poles are chosen. Whatever motion the equator may have is referred to the stars.

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* We have seen that the fixed stars (so called) are not *fixed*.

To the right ascension and declination are attached two columns, giving the hourly change of each. Next follows the sidereal time which the sun's semidiameter takes to pass the meridian: the apparent right ascension is the sidereal time of the instant of apparent noon; subtract the time of the semidiameter passing the meridian, and you have the sidereal time of the sun's western edge or limb passing the meridian. Next follows the equation of time at apparent noon, with the direction for applying it to apparent or sun-dial time, to produce mean time; also the hourly variation. Thus, January 1, 1844, the hourly variation of the equation of time is 1^s,181, which signifies that at the end of every hour of that day the clock is upwards of a second more in advance of the sun-dial than it was at the beginning.

PAGE II. is headed *mean noon*, and gives the apparent right ascension and declination of the *true sun's* centre at the instant when the *mean sun* is on the meridian, and also the equation of time, which is, though very slightly, different from that at the instant of apparent noon. The hourly changes of these three are not, even to the astronomer, perceptibly different from those in page I., and are not repeated. Again, instead of the time of the mean sun's semidiameter passing the meridian (which would be useless, as the mean sun is not a visible object), the apparent semidiameter itself is given, or the arc of the heavens which the semidiameter appears to occupy. These semidiameters are inversely proportional to the distances of the sun from the earth: for instance, January 1, 1844, and January 31, the semidiameters are $16'17''\cdot3$ and $16'15''\cdot0$, which means that the sun is nearer on the 1st than on the 31st in the proportion of $16'15''\cdot0$ to $16'17''\cdot3$, or in that of 975 to $977\frac{3}{10}$. Also in this page is given the sidereal time at mean noon, being the right ascension of the mean sun at mean noon, measured from the apparent equinox.

PAGE III. first gives the sun's apparent longitude, measured from the true equinox, and then the sun's *latitude*. This column may puzzle the reader, for latitude is distance *from* the ecliptic, and the sun's centre is *in* the ecliptic; so that the sun's latitude should be 0° exactly, one would think, and in truth it is never so much as one second of arc, in the column we are describing. This is a point of astronomy with which popular books very properly do not meddle, since the amount of the phenomenon is hardly perceptible even to an astronomer. The fact is, the sun does not describe exactly a great circle of the heavens to a spectator situated at the centre of the earth, if supposed capable of appreciating the hundredth part of a second of arc: but a spectator situated at the centre of gravity of the earth and moon would see it describe a great circle very much more nearly. The ecliptic used in astronomy may be considered as the circle which the sun's centre would appear to describe to this last-mentioned spectator: the former one seeing the sun alternately above and below the circle, to the amount of a fraction of a second at most.

Next follows the *logarithm* of the earth's distance from the sun, which we cannot here undertake to explain: then the moon's semidiameter, on which remarks may be made similar to those already made on the sun's. Then follows the moon's *horizontal parallax*, a term which may be thus explained

If a spectator at the earth's surface were to sink down to the centre, viewing the heavens all the time, it is obvious that though the fixed stars might be too distant to suffer change of place, the nearer bodies, and particularly the moon, would all be somewhat elevated among the fixed stars. To take a familiar illustration, a person descends from the upper window of a house to the lower, and finds that a boy's kite, which just hid the sun when he was at the top, now appears much above the sun. In this case the sun is so distant that his descent does not alter its place, while the kite is so near that the alteration is sensible. The stars are too distant to suffer change of place by a change from the earth's circumference to its centre; the sun and planets are too distant to suffer any change which is worth noting with reference to the use of the globes: but the moon is sometimes changed to the amount of a degree and upwards. The alteration is called *parallax;* the depression of a body, the loss of altitude, or gain of zenith distance, caused by the spectator removing from the centre to the surface of the earth, is the parallax. It changes with the planet's distance from the earth, and also* with its altitude above the horizon. It is nothing when the planet is in the zenith; and greatest, the distance from the earth remaining the same, when the planet is in the horizon. In the last case it is called horizontal parallax: thus by saying that the moon's horizontal parallax is 58′ on a certain day, we mean that the moon's distance is such, that if she were in the horizon of any place, the spectator's descent to the centre of the earth would elevate her 58′ above the rational horizon (page 44) drawn through the centre.

PAGE IV. contains the moon's longitude and latitude measured from the apparent equinox, for every mean noon and midnight in the month, also the moon's age at each mean noon, or the interval since last new moon, to the tenth of a day. Also the mean time of the moon's meridian passage at Greenwich, only to the tenth of a minute, for the purpose of warning those who are to observe the moon on the meridian. The interval between two transits of the moon over the meridian exceeds the sidereal day much more than the solar day exceeds it; or the *lunar day* is longer than the solar day: the more rapid motion of the moon

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* When the horizontal parallax is one degree, the parallaxes answering to different apparent altitudes are as follows:—

Altitude.	Parallax.	Altitude.	Parallax.	Altitude.	Parallax.
0°	60′	35°	49′	65°	25′
10	59	40	46	70	20
14	58	45	42	75	15
20	56	50	38	80	10
25	54	55	34	85	5
30	52	60	30	90	0

producing more of this lengthening effect than the slower motion of the sun, but for the same reason (page 70). It may therefore happen that a whole day by the mean solar clock may elapse without the moon being on the meridian. Thus the moon was on the meridian at Greenwich January 18, 1844, at $23^{h}\ 54^{m}$, or, in common language, at 54^{m} past eleven on the morning of the 19th. Her next transit was on the 20th, at $0^{h}\ 47^{m}$, or at 47^{m} past twelve on the 20th. The whole of the astronomical 19th (page 71) was therefore without a transit of the moon: and similarly it will occasionally happen that the whole of the civil day (from midnight to midnight) is without a transit of the moon. As the moon and sun have the same right ascension, and the same longitude, in the course of the vacant day, or are in *conjunction*, the blank day is filled up in the page with ☌, the sign of conjunction.

To find with sufficient accuracy the time at which the moon passes over any other meridian, note the time which the moon gains upon the sun in 24 hours, and allow such a proportion as the longitude is of 360°, of gain for west longitude, and of loss for east. For example, when is the moon on the meridian in 65° of east longitude, on the astronomical January 14, 1844? She passed at Greenwich, says the Almanac, at $19^{h}\ 59^{m}$ on the 14th, and at $19^{h}\ 1^{m}$ on the 13th, gaining 58^{m} in the day. Now as 360° is to 65°, so is 58^{m} to $10\frac{1}{2}^{m}$, which is what the moon wanted of that gain upon the sun when she was upon the meridian at the required longitude. She was then on the meridian at $19^{h}\ 48\frac{1}{2}^{m}$ by the clock of 65° east of Greenwich, when on the meridian there. But now suppose we want to know when the moon is on the meridian at 100° *west* of Greenwich (when the moon comes *later)* on the astronomical 27th of January, 1844. The moon passes on the 27th at $5^{h}\ 59^{m}$, and on the 28th at $6^{h}\ 45^{m}$, gaining 46^{m}. Now 360° is to 100° as 46^{m} is to 13^{m}, which added to $5^{h}\ 59^{m}$ gives $6^{h}\ 12^{m}$, the time by the clock of 100° west of Greenwich at which the moon passes that meridian.

PAGES V. TO XII. give the moon's apparent right ascension and declination for every *hour* of the month. This degree of minuteness is of course inappreciable on the globe. At page XII. the times of new and full moon and of the two quarters are given, as also the day of the month and hour of the astronomical day at which the moon is in apogee and perigee, or farthest from and nearest to the earth.

PAGES XIII. TO XVIII. are filled with distances of stars from the moon for every three hours at Greenwich, for the purpose of finding the longitude at sea. They have nothing to do with the globe or its use, unless it be that exercises in the use of the flexible arc may be taken from them, by laying down the moon's place from the preceding pages, by means of her right ascension and declination, measuring from the star to the place so laid down by the flexible arc, and then comparing the distance obtained with that given in the Almanac.

PAGES XIX. TO XXI. contain the configurations of Jupiter's satellites, their eclipses, and other phenomena, on none of which it is necessary to say anything here.

PAGE XXII. contains some logarithms which are useful in finding the apparent places of the fixed stars; also the day of the *year* elapsed at each mean noon, the fraction of the year which has elapsed, the mean time of transit (at Greenwich) of the first point of Aries, and the *equinoctial time* of each Greenwich mean noon. This time of transit of the first point of Aries (page 64), or of the apparent equinox, is the time shown by the mean solar clock at the instant when the *sidereal* day begins; in page II. was shown the time by the sidereal clock when the *mean solar day* begins.

Equinoctial time is a recently imagined mode of reckoning time, independently of the meridian of any place. It reckons in mean solar days from the time when the mean sun last coincided with the mean equinox. Thus six o'clock exactly in the evening *at Greenwich*, October 25, 1844, is $218^{d}\cdot332875$ all the world over, the time elapsed since the mean sun was last with the mean vernal equinox being 298 days, 3 tenths, 3 hundredths, 2 thousandths, &c., of a day.

Next to the preceding ordinary matters for every month is a page devoted to the relative position of the ecliptic and equator, and its changes during the year. All the changes here considered are really due to a gradual change in the position of the earth's axis, the main features of which are well represented by the change which takes place in the axis of a top spinning obliquely: the top revolves round its axis, and the axis revolves, but much more slowly, round a vertical line. These effects are too small to be of any consequence on the globe, and the same may be said of the sun's aberration. The motion of the moon's node will be mentioned in a succeeding chapter.

Next follows the ephemeris of the planets. For the principal planets, Mercury, Venus, Mars, Jupiter, Saturn, and Uranus (the motions of which are so well known that the remarks at the beginning of this chapter apply to them), two sets of tables are given: the first for their positions at Greenwich mean noon; the second for their positions when they pass the meridian at Greenwich. These are so printed that the first table is on the left hand side, on opening the book, and the second table on the right; so that for a given planet and month, the book opens to both tables at once. On the left, or in the noon-table, are two compartments, headed 'geocentric' and 'heliocentric.' In the first are given the right ascension and declination of the planet as seen from the earth, the logarithm of its distance from the earth, and the approximate time of its meridian transit, within a tenth of a minute, as a warning to the observer. In the second, or 'heliocentric,' compartment, are given the latitude and longitude of the planet, *as seen from the centre of the sun*, together with the logarithm of the distance of the planet from the sun. It is to be remembered that though the fixed stars are so distant that it matters nothing whether we put the centre of the celestial sphere in the earth or in the sun, it is a very different thing with the planets. The place of a planet in the heavens is *among* the fixed stars, and not in front of them: for though the distances of the planets are as nothing compared with those of the fixed stars, yet they are too great to be appreciated, and both planets and stars appear as at some great, but undeterminable, distance. We shall see more of this afterwards.

In the second, or meridian-transit, table, the quantities given, on which we need say nothing after page 91, are the planets' right ascensions and declinations, their hourly changes, the planets' apparent semidiameter and horizontal parallax, and the sidereal time the semidiameter takes in passing over the meridian.*

The smaller planets, Juno, Vesta, Ceres, and Pallas, (discovered at the beginning of the century,) are not well known, that is, it has not yet been found practicable to predict their places as accurately as those of the other plants, and it would be impossible to explain to the general reader in what the difficulty consists. In order to observe these planets with effect, it is in every point of view desirable to choose the times of observation when the planet is nearly in opposition to the sun. Accordingly, the predictions are only calculated as if the existing data were good for the usual fractions of a second (page 88) during the month preceding and the month following the planet's opposition. For these two months a meridian-transit table is calculated in the same manner as for the other planets; only leaving out what relates to the apparent semidiameters. Another table is given for each of these small planets, which resembles the noon-table of the other planets in every point but these, that it is only for every fourth day in the year, and the right ascensions are given only to tenths of minutes of time, and the declinations and (heliocentric) longitudes and latitudes only to minutes of arc.

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* The planet discovered by Wm. Herschel, which is now generally called Uranus, is still called "the Georgian" in the Nautical Almanac.

We now come to the fixed stars. One hundred of these are selected, among which are the *standard* stars, as they are called, being those which are best known and best adapted for the most accurate use. The following is the list of these stars, the standard stars being in capitals, though, as far as the use of the globes is concerned, and the degree of accuracy which it requires, any star may be considered to be as well known as any other. With these stars are given their right ascensions and declinations, and the yearly variation of each arising from the precession of the equinoxes.

α ANDROMEDÆ
γ PEGASI (*Algenib*)
β Hydri
α CASSIOPEÆ
β Ceti
α URSÆ MINORIS, (*Polaris*)[*]
θ^1 Ceti[†]
α Eridani (*Achernar*)
α ARIETIS
γ Ceti

α CETI
α PERSEI
η Tauri
γ^1 Eridani
α TAURI (*Aldebaran*)
α AURIGÆ (*Capella*)
β ORIONIS (*Rigel*)
β TAURI
δ ORIONIS
α Leporis
ε ORIONIS

α Columbæ
α ORIONIS
μ Geminorum
α Argûs (*Canopus*)
51 (Hev.) Cephei[‡]
α CANIS MAJORIS (*Sirius*)
ε Canis Majoris
δ Geminorum
α^2 GEMINORUM (*Castor*)

[*] The Pole Star.

[†] Meaning the first of the cluster marked *θ*.

[‡] Meaning 51 in the catalogue of Hevelius.

α CANIS MINORIS (*Procyon*)
β GEMINORUM (*Pollux*)
15 Argûs
ε Hydræ
ι Ursæ Majoris
ι Argûs
α HYDRÆ
θ Ursæ Majoris
ε Leonis
α LEONIS (*Regulus*)
η Argûs
α URSÆ MAJORIS
δ LEONIS
δ Hydræ et Crateris*
β LEONIS
γ URSÆ MAJORIS
β Camæleontis
α^1 Crucis
β Corvi
12 Canum Venaticorum
α VIRGINIS (*Spica*)
η URSÆ MAJORIS
η Bootis
β Centauri
α BOOTIS (*Arcturus*)
α^2 Centauri
ε BOOTIS
α^2 LIBRÆ
β URSÆ MINORIS
β Libræ
α CORONÆ BOREALIS
α SERPENTIS
ζ Ursæ Minoris
β^1 Scorpii
δ OPHIUCHI
α SCORPII (Antares)
η Draconis
α Trianguli Australis
ε Ursæ Minoris
α HERCULIS
σ Octantis
β DRACONIS
α OPHIUCHI
γ DRACONIS
μ^1 Sagittarii
δ URSÆ MINORIS
α LYRÆ (*Vega*)
β LYRÆ
ζ AQUILÆ
δ AQUILÆ
γ AQUILÆ
α AQUILÆ (*Altair*)
β AQUILÆ
α^2 CAPRICORNI
α Pavonis
λ Ursæ Minoris
α CYGNI
61^1 CYGNI
ζ Cygni
α CEPHEI
β AQUARII
β CEPHEI
ε Pegasi
α AQUARII
α Gruis
ζ Pegasi
α PISCIS AUSTRALIS (*Fomalhaut*)
α PEGASI (*Markab*)
ι Piscium
γ Cephei

Of these stars, the two which are nearest the pole, α Ursæ Minoris (the pole star) and δ Ursæ Minoris, are so much affected by the precession of the equinoxes and the other slight changes which the so-called fixed stars undergo, that it is worth while to give a table of their right ascensions and declinations for every day in the year; which is accordingly done for the moments at which they pass the meridian at Greenwich, south of the pole. The other 98 stars have similar tables given for every tenth day of the year, for January 1, 11, 21, 31; February 10, 20, &c.

Next follows a table, for each day of the year, of what are called *moon culminating* stars. One of the modes of finding the longitude of a place is observation of the exact time (usually by the sidereal clock) at which the moon's centre passes the meridian. If clocks were perfect, this would be enough: but since this mode of finding longitude requires the utmost exactness of observation, and since the best clocks slightly vary their rate of gaining or losing, it is desirable to correct the clock by observations of stars made as near as possible to the meridian passage of the moon, so that the dependence of the observer upon his knowledge of the rate of gaining or losing of his clock may have reference to as short a period as possible. Accordingly, stars which pass the meridian soon before or after the moon (called *moon-culminating* stars) are selected for each day, and their right ascensions (declinations having nothing to do with the determination of time) are given for their Greenwich meridian transits. The right ascension of the bright edge or limb of the moon is also given for the Greenwich transit, both over the visible meridian and the opposite or invisible part.

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* Hydra et Crater means the constellation Crater simply.

Next follows a list of stars occulted by the moon, or over which the moon passes, at any time when she is above the horizon at Greenwich, and visible. After this there is a description of the eclipses of the sun and moon which take place during the year, and a table of remarkable phenomena, as conjunctions, &c., with the times at which they take place.

The publication which comes next after the Nautical Almanac is White's Ephemeris, in which enough is given to obtain the positions of the sun, moon, and principal planets, with sufficient exactness for the user of a globe. In one respect it is even more convenient than the Nautical Almanac, since it gives the longitude and latitude of the planets as seen from the earth for every sixth day; and, on a globe which has a divided zodiac, longitudes and latitudes are more convenient than right ascensions and declinations.

CHAPTER IX.

Problems connected with the manner in which Solar Phænomena depend on the latitude of the place.

THE problems in this chapter* are those in which the terrestrial globe is used astronomically. For this purpose the horizon of the terrestrial globe is furnished in the same manner as that of the celestial, and two different species of ecliptics are laid down on the globe. The first is the ordinary ecliptic; and as it does not matter where it intersects the equator, 60° East and 120° West of Greenwich are chosen for the intersections. The other ecliptic is called the *analemma:* it is not a circle going round the globe, but an oval figure, on which the days of the months and degrees of the zodiac are marked in such a manner that, on bringing any day to the meridian, the sun's declination for that day of the month is seen on the brazen meridian, and its degree of the zodiac on the analemma itself. Thus, both on the ecliptic and on the analemma it will be seen that the days on which the sun has 10° of north declination are the 16th of April and the 27th of August. By reading first on one and then on the other, exercises confirmatory of each other may be obtained.

The sun or a star (page 63) passes over head, or is vertical, at all places which have its declination for their latitudes. Between the tropics the latitude of every place is, at two days of the year, equal to the sun's declination; at the tropics the same thing takes place once only; outside the tropics never.

To what places is the sun vertical on the 22nd of April? Bring April 22 on the ecliptic or analemma to the meridian, and it will be seen that the sun has 12½° of north declination. Turn the globe, and nearly under 12½° of north latitude will come Gondar, Socotra, Madras, Camboja, Dawson Island, Point Gallinas, &c. &c. To find when the sun is vertical at a given place, invert the process, find the latitude of the place, and find on the analemma or ecliptic the days on which the sun has a declination equal to that latitude. At Trinidad, for example, the sun is vertical on the 17th of April and the 25th of August; from April 17 to August 25 the noonday sun is to the north of the spectator. The reader may exercise himself on the following problem:—In about what latitude is the noonday sun north during sixty days of the year?

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* It is presumed that the reader of the preceding chapters will now be able to dispense with very full explanation: accordingly, a greater degree of condensation is introduced.

To find the place over which the sun is vertical at any hour of any day. Find the declination for that day, which is the latitude of the required place. The sun is vertical only at noon; accordingly it must be found in what longitude it is noon at the given place. For instance, where is the sun vertical when it is eight in the morning at New York on the 18th of August? The latitude of the place is 13°. Now at 8 A.M., in any place, it is noon at places which are four hours or 60° east of that place. New York is 74° west of Greenwich; 60° east of New York is 14° west of Greenwich: accordingly the required place is in long. 14° W., lat. 13° N., which gives Medina in Senegambia, nearly.

To find when the sun is rising, on the meridian, and setting, at a given day and hour. Find by the last problem where the sun is vertical at the instant in question, and make that place the top of the globe or the pole of the wooden horizon, as in page 32 (remembering to elevate the south pole for south latitude). Then it is day at every place above the wooden horizon, and for a very little way below it (from the effect of refraction); and it is night for all the rest of the globe. At all the places on the wooden horizon the sun is either rising or setting; rising to those at the western edge, setting to those at the eastern. At all the places on the brazen meridian it is noon or midnight; noon to those above the horizon, midnight to those below it. Thus for 8 in the morning at New York on the 18th of August, we elevate the north pole. 13°, and then bring 14° W. longitude to the meridian. Then the sun is rising on the west of North America, and so on, down to the newly discovered southern lands; while it is setting to the inhabitants of a line drawn up Asia through the middle of Hindostan: it has just passed the meridian at one part of Europe.

In the preceding problem we can also find the altitude which the sun has at any part of the globe to which it is visible. Clamp the flexible arc to the top of the brazen meridian (page 33), and then bring it over the required place. The altitude of the sun is then shown by the altitude of the place itself above the wooden horizon.

If, instead of the place itself at which the sun is vertical, the antipodes of that place be made the top of the globe, which must be done by elevating the other pole, &c., then everything is reversed. All above the horizon is dark, and all below light; night is beginning on the western edge, and day on the eastern, &c. The altitude last found shows the depression of the sun below the horizon. It is customary to suppose that twilight begins or ends when the sun is 18° below the horizon. Assuming this (the reader may put any other depression which he prefers), and making, as just directed, the point* of darkest midnight the top of the globe, all the points which are on a parallel to the wooden horizon at 18° distance from it will be on the verge of twilight: those on the eastern side will have their morning twilight just commencing; those on the western side will have their evening twilight just ending.

The day's work of the sun can be easily pointed out for any day, without the necessity of first finding where the sun is vertical; but the preceding mode saves the use of the brazen parallel, and gives all the accuracy of the equator (page 84). Elevate the pole by the sun's declination for the day; and having brought the given place to the brazen meridian, turn the brazen parallel until noon is also on the brazen meridian. Then turn the globe from west to east for an afternoon hour, or from east to west for a morning hour, until any hour required is on the brazen meridian: all above the horizon is then light, the western horizon is rising, &c. &c., as in the last problems. There is no occasion now to point out how to ascertain the parts of the earth at which the sun never sets on any given day, or never rises; nor how to find where there is twilight all night long, by rough trial with the flexible arc.

To find where any star or planet is vertical at any given hour, find the time at your place when the star is on the meridian (by the celestial globe, page 84). Elevate the terrestrial globe for the declination of that star, and, bringing your place to the brazen meridian, bring the star's time of transit on the brazen parallel also to the brazen meridian; then, turning the globe from west to east for a subsequent time, or from east to west for preceding time, turn it until the time you want on the brazen parallel comes on the brazen meridian. Then the top of the globe (which will have the same latitude as the star's declination) will be the point at which the star is vertical. All that relates to the star's rising, setting, &c. is exactly as in the preceding problems. In the case of an eclipse of the moon, save some trouble by remembering that the moon, when eclipsed, is just opposite to the sun, or is over the point of darkest midnight.

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* It will be convenient to call the point of the earth over which the sun is vertical the *point of brightest noon*; and its antipodal point the *point of darkest midnight*.

The times of sunrise and sunset at any place on any day can be found in the preceding mode by bringing the place to the western and eastern horizon, and then reading the hour on the brazen parallel. They can also be found as in page 85, and the two results may be compared. The time of sunrise being found, that of sunset is found by subtracting it from 12 hours: thus, when the sun rises at 4 in the morning, it sets at 8 in the evening. It is hardly worth while, in this class of problems on the terrestrial globe, to make those efforts at accuracy which are of some interest on the celestial globe: the equation of time, for instance, is not worth notice in the rough results of the present chapter.

The celestial globe being elevated for a given latitude, it is clear that no point of the heavens can set, unless its distance from the north pole be greater than the latitude; that is, unless its declination and the latitude be together less than 90°. The portion of the heavens (page 46) which never sets at any place is called its *circumpolar* portion, and the same name should be given to the opposite and equal portion round the other pole, which never rises. In *north* latitude 40°, for instance, every star is circumpolar and never-setting which has a *north* declination of 50° or more; and every star is circumpolar and never visible which has a south declination of 50° or more. Similarly a star of 50° of declination is circumpolar at every place which has more than 40° of latitude. A fixed star is always of the same sort with respect to any place: it either always rises and sets, or it is always visible, or always invisible. But the sun, which varies its declination from 23½° south to 23½° north, is at certain parts of the earth circumpolar during a portion of the year. When the sun is at the equator it is nowhere circumpolar: it is seen at both poles. When it has gained 5° of *north* declination it is visible all through the 24 hours at every part of the earth which is within 5° of the north pole, or has more than 85° of north latitude; but it is then invisible throughout the 24 hours at every place which is within 5° of the south pole. When the sun is at the northern (or, as we call it, *summer*) solstice, all within the arctic circle is permanently light, and all within the antarctic circle permanently dark. It is usual* to talk of the places within the arctic and antarctic circles having days of several of our days in length, and of the pole having only one day and one night in the whole year.

To find when the day begins to be all daylight or all night in any arctic latitude, and how long the sun continues above the horizon, subtract the latitude from 90°, and make the remainder the sun's declination. Look on the analemma for the first and second days on which the sun has this declination, first of the same name as the latitude, next of the contrary name. Thus are seen the days at which perpetual light begins and ends, and also perpetual darkness. For example, what are the terms of light and darkness in 75° of *north* latitude? Take 75° from 90°, and 15° remains: by the analemma (or by the ecliptic) it appears that the sun has 15° of *north* declination on the 1st of May and the 12th of August, between which intervals there is perpetual light in 75° north latitude, and perpetual darkness (so far as sunlight is concerned) in 75° south latitude. Again, the sun is in 15° of *south* declination on the 3rd of November and the 8th of February, and from the first-named day to the second it is perpetual darkness in 75° north latitude, and perpetual daylight in 75° south latitude.

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* If by a *day* we mean the time of *sunlight*, this phraseology is correct; but then it is absurd to say that 365 *days* make a year: 365 days make only half a year; and it takes 365 days and 365 *nights* to make a year. Also it is absurd to talk of the night being a part of Mon*day*. But the truth is, that in astronomical language, and in common language whenever any chronological notion is implied, the day means one diurnal revolution of the sun, and is not a distinct thing from night, but includes it: every day, in our latitudes, consists of *daylight* (or *day* in the first sense), and *night*, or darkness. According to this mode of definition there is no day anywhere of more than 24 of our clock hours; but within the arctic circles there are days in the middle of summer which have no night, and days in the middle of winter which have nothing but night. And at the pole the days throughout half the year are nothing but daylight, and nothing but night throughout the other half.

For the converse problem, namely, to find in what arctic latitude the permanent appearance or disappearance of the sun lasts any given number of days, halve the number of days, and reckon off that number of days from the 20th of June. Bring the day thus obtained, as seen on the analemma or on the ecliptic, to the brazen meridian, and there is seen on that meridian the declination of the sun at the beginning and end of the phænomena required. Subtract that declination from 90°, and the latitude required is given. Thus to know where the continual light lasts 90 days, we reckon 45 days from the 20th of June, which brings us to August 4: which, brought to the brazen meridian on the analemma, is at 17° on that meridian. Take 17° from 90°, and we have 73°, the latitude required.

But in these problems an allowance is to be made for the refraction of light, which, by making the sun visible before it really rises, and after it really sets, prolongs the continual daylight, and shortens the continual night, by a period which varies from about 2 to 24 days, and is greatest at the arctic circles and least at the poles.

We have thus found the longest daylight at any place within the arctic circle: an entirely different method must be pursued when the place is one at which the sun always rises and sets. Let the sun be at the summer solstice, and find (page 85) the *apparent* time of sunrise, and reduce it to mean time by the equation of time. Double this hour of sunrise, and the length of the *shortest* daylight is obtained: subtract the length of the shortest daylight from 24 hours, and the length of the longest daylight is obtained. Thus in a latitude in which the sun rises at 4 o'clock on the day of the summer solstice, the length of the shortest daylight is 8 hours and that of the longest daylight 16 hours. But refraction lengthens both the longest and shortest *days*, as they are called.

To find roughly in what latitude the longest day is of any given length, proceed as follows:—Suppose it required to find in what latitude the longest day is 17 hours, or the hour angle at sunrise 8½ hours. Bring the summer solstice to the brazen meridian, and also the XII on the brazen parallel: and then turn the globe 8½ hours either way. Then elevate* or depress the globe steadily, taking care it does not turn, until the summer solstice is on the horizon: then the number of degrees by which the globe is elevated is the latitude required. In the present instance, the result will be 53°; calculation gives $8^h\ 21^m$ for the half of the longest day in that latitude. The necessary imperfections of the wooden horizon prevent this result from being more accurate.

The globe may be made an astronomical instrument for determining within a few minutes the time of day when the sun shines, provided that the wooden horizon be very nearly level, and the brazen meridian be made to point due north and south. The last can be done tolerably well by the compass, when the variation for the place is known. Stick a small pin upright into the globe, at a declination equal to that of the sun for the day, the globe being elevated for the latitude of the place. The meridian being north and south, and the globe placed in sunshine, turn it until the pin casts no shadow, or points directly towards the sun. The number of hours from noon may then be read by means of the equator or of the brazen parallel, which will give the sundial time from noon. To this the equation of time may be applied, if thought necessary. Instead of a pin, a pencil may be held upon the globe; and if, when the pencil is at the meridian, the brazen parallel be brought to the brazen meridian at XII, the hours through which the globe is turned before the pencil throws no shadow may be seen at once. The reader must not expect much to come from this method; the inversion of the problem, namely, the fixing of the meridian north and south by means of the time of day, would be done with more accuracy.

The meridian being north and south, the globe properly elevated, and the place upon the meridian, the sun will then shine upon the globe as it does upon the earth, and the line which divides the bright part of the globe from that which is in shade will contain the parts of the earth at which the sun is rising or setting. A pin held any where on the globe upright, that is, pointing at the centre of the globe, will have its shadow in the same direction as those who are at the part of the earth which the position of the pin represents.

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* Begin with the globe much or little elevated, according as the day differs much or little from 12 hours.

CHAPTER X.

Description of the apparent motions of the moon and planets among the stars.

THE description of the motions of the moon and planets brings no new problems forward. The almanac must give the places of these bodies; for it would be impossible to trace out their motions as seen from the earth, in the same manner as that of the sun is done in the ecliptic. Nevertheless, when the place of the body for the day is found in the almanac, and thence laid down on the globe, any of the preceding problems may be worked in the same manner as for a fixed star.

But, inasmuch as the globe and almanac combined may be made to answer to an actual look at the moon or planet in the heavens, and an observation of what stars are near, it is desirable to make them supply the place of the heavens, in learning the visible motions of the solar system. With the actual motions we have, as already explained, nothing to do: the object of this chapter is to help the student in forming a just idea of the apparent motions.

Nothing describes a daily *circle* in the heavens, unless its declination remain unaltered. If the declination alter slowly, the curve described is a spiral encircling the sphere in very close folds, each fold being one diurnal revolution. The sun describes such a spiral in the course of the year, its daily folds coinciding nearly with the two tropics and with the equator, at different times of the year. The moon does the same, and gets to a greater declination than the sun. But these spirals are never mentioned, for it is easy to decompose the motion, and to imagine the simple diurnal motion taking place *with* the globe, combined with the orbital motion *on* the globe.

To avoid considering too many combinations of motion at once, we may as well suppose the diurnal rotation to cease, so that alternations of rising and setting do not take place. The so called fixed stars then become really fixed; and the sun, moon, and planets exhibit nothing but their orbital motions, which can only be detected by careful observation, when mixed up with the overpowering magnitude of the diurnal motion. As much motion may be allowed to the heavens, when wanted, as will bring the part he wants to examine over the spectator; all the stars and planets are to be supposed visible in sunlight: in fact, the reader must be imagined to have the power over the heavens which he has over his globe, to turn it or make it stand still, and to enlighten any part of it permanently. If this globe were to turn round every half minute, a person who had to examine the track of some little bodies which move *upon the globe* would have his work much increased; and when it was done, and he wished to describe the results, he would omit all mention of the periodical motion, and would speak as of a globe at rest, and bodies moving upon it. The reader who is not much used to the subject must be very particular in thus getting rid of the diurnal motion: after learning the peculiar motions of the planets, he may then imagine the diurnal motion to be combined with them, as soon as he pleases.

Again, since the effects which we are to describe take much longer periods than the diurnal revolution, we may perhaps produce clearness of illustration by supposing a year (a revolution of the sun) to pass in an hour; and all other motions to be in proportion. The sun will then be seen moving along the ecliptic from west to east, and the ecliptic may be imagined to be traced out by a bright line in the heavens, as also the equator.

When the sun has described a revolution in the heavens, leaving a bright spider-line to mark the track of its centre, and beginning at the vernal equinox, the spectator, with ordinary notions, will expect to see the track end where it began; that is, he will expect to see a perfect circle, with the vernal equinox of the new year coinciding with that of the old one. Instead of this, however, he would see that the new equinox is a little to the west of the former one, and the orbit of the second year is a new spider-line, very near that of the first, but not coincident with it. Every year a new fold of a spiral is marked out, crossing the equator at points more westerly than the fold of the preceding year; and it would soon be apparent that 26,000 folds, or thereabouts, would be described upon the globe. By an easy fiction, the sun is supposed to move in a circle, which circle, without altering the distance of its solstices from the equator, slips, as it were, slowly round from east to west, while the sun traverses in it from west to east. But this fiction, like many *others in astronomy*, takes its rise from the addition of new discovery to old notions: the sun was once supposed to move in a real circle, and when this spiral motion was discovered, the slipping of the circle was a natural way of describing it. This is the precession of the equinoxes mentioned in pages 73, 74; where it is convenient to suppose the equator to slip on the ecliptic: either supposition completely describes the character of the sun's changes relatively to the equator. On the inequality of the sun's motion see page 80: Chapter VII. contains the developments of this part of the subject.

Let us neglect the precession of the equinoxes, since it is very small, and suppose that the motions of the moon and planets are referred to the ecliptic, and their places ascertained by their *celestial* latitudes and longitudes (page 74). And first as to the moon.

The motion of the moon with respect to the ecliptic is an exaggerated representation of that of the sun with respect to the equator, except only in this, that whereas the sun rises in declination to 23° 27′ from the equator, the moon only rises in latitude to 5° 9′ from the ecliptic. Again, if the moon's centre were to leave a thin streak in the heavens, that streak would not be a circle repeated over and over again, but a spiral encompassing the zodiac with successive folds, every fold crossing the ecliptic to the westward of the preceding fold. This again is represented by a fiction: the moon's orbit is said to be a circle inclined at 5° 9′ to the ecliptic, which circle slips backwards on the ecliptic, or from east to west, while the moon moves forward from west to east in the circle. The places in which the apparent path of a planet cuts the ecliptic are called its *nodes;* the node is called *ascending* when the planet passes through it to the northern side of the ecliptic, *descending* when to the southern side. The fictitious circle which is called the moon's orbit slips backwards (or from east to west) in such a manner that its nodes move completely round in $18\frac{6}{10}$ Julian years of $365\frac{1}{4}$ days each: or the fictitious node of the circle recedes $3\frac{2}{10}$ minutes every day. The average apparent diameter of the moon is 31 minutes, and that of the sun 32 minutes. Those who have been accustomed to think of the moon's orbit as a fixed circle in the heavens will be surprised to hear that its intersection with the ecliptic slips back a whole* *sun-breadth* in every ten days.

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* And perhaps they will be as much surprised (page 19) to be told that if the sun were to move its whole diameter every ten days, it would be more than 18 years in making the circuit of the heavens.

The consequence of this rapid change is that the moon does not always pass over and hide the same stars, as it would do if it moved in a fixed orbit, but passes over one star for a few revolutions and then leaves it for nine years, when it takes it again in approaching to or receding from the other node. Thus in 1834, February 6, there was an occultation of 26 Sagittarii. No such thing happened again in that year, and the moon was at that time very close to her *descending* node, or moving from north to south latitude. At the end of a little more than nine years, in 1843, May 16, and July 10, we find 26 Sagittarii again among the occulted stars, and at both times the moon is very near her *ascending* node, or moving from south to north latitude. The fictitious circular orbit has slipped half way round in the nine years and odd months mentioned.

The moon moves (from west to east) round the heavens, that is, from a certain longitude to the same longitude again, in 27 days, 7 hours, 43 minutes, on an average. But the striking appearances of the increase and wane of the moon depend upon her position with respect to the sun. We have nothing here to do with these changes, in treating merely of the use of the globes, and of the phænomena which can be illustrated by them. When the sun and moon have the same longitude, it is new moon: when their longitudes differ by 180°, it is full moon. For the same reason as (page 70) the solar day is longer than the sidereal day, it follows that the interval between two full moons is longer than a complete revolution of the moon in the heavens: it is, in fact, one time with another, 29 days, 12 hours, 44 minutes. The interval from new moon to new moon is the original *month*, but to avoid confusing it with the arbitrary months of the kalendar, it is generally called a *lunation*.

The actual motion of the moon is much more removed from uniformity than that of the sun; and astronomers use a *mean moon** in the same manner as the mean sun is used (pages 70,

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* There is another fictitious moon, of a much more singular character, the *Kalendar Moon*. The moon which regulates the finding of Easter is not the mean moon, but a different thing altogether. It was kept as close to the mean moon as convenience, coupled with certain notions about the festival, would allow: but it is generally a day or more distant from the mean moon. The discussion which took place in 1818 and again at the end of 1844, partly arose from people in general supposing that the moon of the Kalendar is the moon of the heavens. See an article in the *Companion to the Almanac* for 1845. This unnecessary discussion will be revived from time to time, until some proper explanation of the legal meaning of Easter is *added to the prayer-books* of the Church Establishment.

81). This mean moon is made to move uniformly in the equator, or in the ecliptic, as wanted. But since it is very necessary to be able to find, within a few minutes, the time of real new and full moon, I have reprinted a method in the appendix (No. ii.), which will succeed in giving the true times, most frequently within a quarter of an hour, and always within half an hour, for any year from B.C. 1000 to A.D. 2000.

To describe the irregularities of the moon's motion would be useless for any purpose connected with the globes: there is nothing for it but to take her place from the Nautical Almanac or from White's Ephemeris, if even so much as the accuracy of a globe is contemplated. And for this purpose the *parallax* (page 91) may require attention. Suppose, for instance, that on laying down the moon's position on a globe rectified for the place, the altitude (page 66) is found by the flexible arc to be 25°. Let the horizontal parallax, as taken from the almanac, be 50′. Then since (page 91) every degree of horizontal parallax gives 54′ of parallax at 25° of altitude, it follows that 50′ gives 45′. That is to say, the moon's place from the almanac, which is as seen from the centre of the earth, must be lowered 45′ in altitude, to make her appear as seen from the spectator's part of the surface of the earth. The average horizontal parallax of the moon is 57′, and it varies from 53′ to 61′.

The space of nineteen years is about 7½ hours longer than 235 average lunations, when there are five leap-years in it, and about 16½ hours shorter, when there are only four. Roughly speaking then, with here and there a day of error, it is correct to say that in nineteen years the new and full moons begin to return to the same days of the months. To test this, let us take the year 1806, and remove *two* cycles (of nineteen years each) forward, which brings us to 1844:—

1806.		1844.
Jan. 5, 1^{m} after midnight	Full moon	Jan. 5, $5\frac{1}{2}^{h}$ afternoon
Jan. 19, 8^{h} evening	New moon	Jan. 19, 6^{h} afternoon
Feb. 3, 11^{h} evening	Full moon	Feb. 4, 9^{h} morning
Feb. 18, 3^{h} morning	New moon	Feb. 18, 9^{h} morning
Mar. 4, 9^{h} evening	Full moon	Mar. 4, 9^{h} evening
Mar. 20, 7^{h} morning	New moon	Mar. 18, midnight

The late Mr. Frend, in his *Evening Amusements* (a series of nineteen volumes, published from 1804 to 1822, and which can be frequently obtained from the second-hand booksellers) gave a yearly description of the principal phenomena of the moon and planets, which might still be used with advantage, as far as the moon is concerned: not merely because the discrepancies between the present and former state of things will be small, but because they are instructive as showing the gradual departure of one cycle of nineteen years from those which precede. The year 1806 has 1825 for its immediate successor, and 1844 is its next representative. We make an extract from the *Evening Amusements* for 1806, supplying in Italics the corrections which are necessary for 1844. The place supposed is Greenwich:—

"*January*, 1806. The Moon, at her first appearance on the first day of this month, is seen in the neighbourhood of the Pleiades, these stars being to the east of her (*almost directly above her*); and near nine (*at 53 minutes past eight*), when she is on the meridian, she has approached to about half a degree (*within less than 2 degrees*) from Heta (η), the principal of them. Her course is directed to the twelfth* (μ) of the Twins, and she therefore passes above Aldebaran, and between the second and sixth (β and ζ) of the Bull. . . . On the second, the moon is considerably to the east of the Pleiades, and on the meridian at 51 minutes past nine (43 *minutes past nine*), being in a remarkable position in the constellation of the Bull, about fourteen (*about twelve*) degrees to the east of the Pleiades, between nine and ten (*about twelve*) degrees from the second (β) of the Bull, which is higher up to the east of the meridian, and about twelve (*about fourteen*) degrees from the sixth (ζ), which is lower down and also to the east of the meridian. Aldebaran is now almost under (*a very little west of*) the Moon, and between nine and ten degrees from it. . . On the third, she is seen on the meridian at 55 minutes past ten (34 *minutes past ten*) and to have passed between the two horns of the Bull, and at her first appearance to be near (*some degrees to the west of*) a star . . . of the Bull . . now called by astronomers 132 . . . She is now nearer to the sixth (ζ) than to the second (β) of the Bull, and is approaching to the twelfth (μ) of the Twins, which star she will pass about six on the following morning (*about eight on the following evening*) within the distance of a degree."

A part of the difference between the two years is to be attributed to the fact that the orbit does not come to its former position in 19 years, but in 18 years and $\frac{6}{10}$ of a year, so that the circumstances which depend on the latitude are not the same as before. But still more depends on the irregularities of motion in the orbit, of which we cannot here give the explanation.

The period of nineteen years, the foundation of our lunar ecclesiastical kalendar, is likely enough to be confounded with another remarkable period, of 18 years and 10 or 11 days, according as the 18 years have 5 or 4 leap-years. To this period the Chaldean name of *Saros*[*] has been applied. Since the moon's node moves backward on the ecliptic, it is clear that the interval between two passages through one node must be less than the sidereal revolution of the moon, and still less than the lunation. In fact, 242 *nodical* months, or intervals between two passages through the ascending node, are almost exactly equal to 223 average lunations. Now we know that an eclipse of the sun is the consequence of new moon happening when the moon is very near a node, and that an eclipse of the moon is the consequence of full moon happening when the moon is very near her node. If the lunation were always at its average, and if 223 lunations were exactly equal to 242 nodical months, the eclipses which happen in any 223 lunations (of the moon certainly, and of the sun, as seen from the centre of the earth) would be repeated again in the next 223 lunations. The suppositions are not true, but they are so near the truth as to make it much more likely than not that whenever an eclipse happens, another will happen in 18 years and 10 or 11 days. Thus, in the year 1830, there were eclipses of the sun on Feb. 23, March 24, August 18, and Sept. 17. In the year 1848 there will be eclipses of the sun on March 5, April 3, August 28, and Sept. 27. In 1830 there were eclipses of the moon on March 9 and Sept. 2. In 1848 there will be eclipses of the moon on March 19 and Sept. 13. It so happens, then, that every eclipse of 1830 has its counterpart in 1848; but it will happen now and then that an eclipse has not its counterpart in the following period, or else that one comes in which was not seen in the preceding period.

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* Mr. Frend used the *number* of the letter in the Greek alphabet, calling α of a constellation the first, β the second, &c.

There is nothing peculiar to eclipses in which the globe can be made of any use. It should be remembered that an eclipse of the sun and one of the moon are distinct species of phænomena. An eclipse of the sun is an accident of the spectator's place: the moon comes between a part of the earth and the whole or part of the sun; those who are on that part of the earth lose the whole or part of the sun, and those who are on adjacent parts of the earth see the sun as usual. But an eclipse of the moon arises from the planet losing her light by coming wholly or partially into the earth's shadow: all who can see the moon begin to lose sight of her at the same instant. The question where the beginning of an eclipse of the moon can be seen, is precisely the same as that of where the moon herself can be seen at the time named in the almanac for the beginning of that eclipse. But all matters connected with an eclipse of the sun require so much minute calculation connected with the parallax both of the moon and of the sun, that it is idle to pretend to do anything with it upon the globe.

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[*] It is not very certain that the Chaldean Saros was this period of 18 years: see the *Penny Cyclopædia*, article "Saros."

It may be more to the purpose here to take some slight notice of the problem of finding latitude and longitude. With regard to the problem of finding latitude, the following assertions are so easily made out to be true by a person who has in any degree mastered the meaning of the globe, that I merely put them down as exercises:—1. When a star does not set, the half sum of its greatest and least altitudes is the elevation of the pole, or the latitude of the place. 2. If a star be north of the equator, its meridian altitude diminished by its declination, and the remainder subtracted from 90°, gives the latitude. 3. If the star be south of the equator, the sum of its meridian altitude and declination, subtracted from 90°, gives the latitude. These results are made slightly untrue by the *refraction*, or bending which takes place while the rays of light pass through the atmosphere, for which accordingly a proper allowance must be made.

The latitude of a place gives an absolute phænomenon, the altitude of the pole. There is not a star in the heavens whose motion does not depend upon the place of the pole. Accordingly, as we see above, the position of the pole can be determined as soon as any star of known declination has had its meridian altitude observed: and there are various other methods, besides those above noted, by which the latitude can be found from observations of one or more stars (the word star including sun, moon, or planet). But longitude does not give any absolute phænomena except those which depend upon time; all unchanging appearances are seen by those in one hour (or 15°) of west longitude, just one hour after they are seen at Greenwich. There is no mode of finding longitude measured from Greenwich except ascertaining what time it is at Greenwich, and also at the place, for some one absolute moment of time. Suppose, for instance, there is a clock at a certain place west of Greenwich, regulated by daily observations of the celestial bodies. A good watch is set by this clock, carried to Greenwich, and found to be one hour too slow: it is then clear that the place is one hour west of Greenwich. If watches were perfect, this method would be perfect: recent improvements in *chronometers* (as astronomical watches are called) have made it a valuable auxiliary to other methods.

Again, suppose there is a phenomenon which can be seen at both places, and which happens at the same absolute instant at both, such as the beginning of a lunar eclipse. If two observers, one at each place, mark the time by two clocks which are right for the two places, they will, on comparing their observations, see how much their clocks differ, and from thence how much the two places differ in longitude. And even if there be a phenomenon (as for instance the beginning of a solar eclipse) which does not begin at the same absolute time at both, yet if it can be told by calculation how much earlier it happens at one than at the other, an observation made as before at both places will easily find their difference of longitude. Nor need the phenomenon be one which is very striking to the world at large. For instance, the method of *lunar distances* depends upon observing at any one moment the distance of the moon from a star, and finding out by calculation (with help of the Nautical Almanac) at what time the moon has that distance from the star at Greenwich. An observer at sea measures the moon's distance from Aldebaran, say exactly at *two* in the afternoon, *by the time at his place,* and after calculating the effect of parallax and refraction finds that, if he had been at the centre of the earth, that distance would have been exactly 30°. Suppose he finds by calculation that it is exactly *one* o'clock P.M. at Greenwich when the moon's distance from the star, reduced to the centre of the earth, is 30°. He knows then the time at his place is one hour faster than Greenwich, or that his longitude is 15° east. [In all these illustrations we take round numbers for facilitation; it would not aid comprehension of the main principle of operation if we introduced the odd minutes and seconds.] The moon is chosen in this method on account of the rapidity of her orbital motion, more than a degree in two hours, one day with another. Any of these methods might easily bring out correctness within a minute or two of time: but when the fractions of a minute are attempted, the want of perfection in the lunar tables (page 88) stands* in the way of getting extreme accuracy, unless many observations can be made, and the average of their results taken. Add to this, that at sea there is difficulty in making the observations very accurate. Even at this day it is difficult to find a ship's place on the earth within twenty miles of the truth, by means of one observation.

The distance of a body from the earth has nothing to do with the globe, which represents only the apparent heavens (pages 18-20). It may nevertheless be worth notice that neither the sun nor moon always appears greatest at the same part of the orbit. The point at which a planet appears greatest, or at which it is nearest to the earth, is called its *perigee:* that at which it appears least, or at which it is farthest from the earth, is its *apogee.* Now both perigee and apogee of the sun and moon are, as is said, in a state of progressive motion from west to east; by which it is meant that the position of the body in which it appears greatest or least for any one revolution is more advanced than for the preceding revolution. For instance, in January, 1844, it appears by the almanac that the moon's apparent diameter† is greatest on the 15th, at which day her longitude at noon is 239°. Turn forward to July of the same year, and we find that the moon's diameter is greatest on the 26th, at which time her longitude is 261¼°. Here then, in six lunations, is an advance of 22¼° in the place of the perigee. The average motion is 40° 49′ in a year, or a complete revolution in something less than nine years. The apogee also revolves at the same rate, and the apogee of one revolution is never exactly opposite to the perigee of the same. For instance, in August, 1844, the moon is in apogee at 10 in the morning of the 7th, and in perigee at 3 in the afternoon of the 21st. Her right ascensions at these times are $3^h\ 45^m$, $16^h\ 14^m$, the second of which exceeds the first by 29 minutes more than 12 hours, so that the two points are not opposite. The sun's perigee also has a slow advancing (or from west to east) motion of about 12″ in a year.

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* The practical difficulties in the way of finding the longitude, and the Act of Parliament (now repealed) offering a reward for improvement in chronometers or in the lunar tables, for a long time led persons ignorant of the subject to suppose that there was a concealed mystery about longitude which might be discovered by mere thought, without either watchmaking or astronomical observation. There are still those who waste their time in endeavouring to produce new solutions of this great question: and some think that there must be a peculiar connection between it and some of the old difficulties of geometry, such as that of squaring the circle. The mathematical sciences enjoy in a peculiar degree a disadvantage which belongs more or less to every branch of knowledge, namely, that those who have not studied are but rarely able to estimate the difference between sense and nonsense, in the assertions of those who pretend to have studied. Perhaps there is hardly an educated person but has some acquaintance who thinks he has made a discovery, and inveighs against the world, and particularly those who have made his subject their pursuit, for not examining his claims. Many such persons have not reading enough to know that their peculiar ideas have been examined and found unsound long before they were born. Many have a mode of reasoning which they prefer to mathematical demonstration, of which they know nothing. The countenance which such persons often receive from those who have not attended to the subject, is a bad thing for the speculators themselves, and for the spread of real knowledge: sometimes it leads to ludicrous results. It is not very long since a scientific body in this country received from a public functionary whose rank made it difficult to refuse compliance, a request that they would examine the discoveries of a self-created astronomer among whose other notions was firmly fixed the following—*once one is two.*

† The reader will take care not to confound this with the time when most of the moon is seen, or with the full moon.

Great care must be taken, in thinking of celestial revolutions, not to confound a revolution from 0° of longitude to 0° of longitude again with a revolution round the heavens. The zero of longitude is continually moving backwards (page 73), and every advancing motion in longitude is 50″ per annum greater in appearance than in reality. Thus, though the sun's perigee moves only 12″ every year, it increases its longitude 62″ every year, because the equinoxes move back by 50″ every year.

The perigee and apogee of the sun and moon are connected with the orbital motions in a remarkable manner: the motion in longitude is greatest at the perigee and least at the apogee. On August 7, 1844, at which the moon is in apogee, her longitude at midnight is 53° 50′, and at noon 59° 44′, giving 5° 54′ motion in 12 hours; but on the 21st, when she is in perigee, her longitude at noon is 243° 48′, and at midnight 250° 52′, giving 7° 4′ in 12 hours. The same thing happens (as we have seen, page 80) with respect to the sun.

I now proceed to give some account of the motion of the planets Mercury, Venus, Mars, the small planets (Vesta, Juno, Pallas, Ceres), Jupiter, Saturn, and Uranus. The satellites of the last three need not be considered, as there is nothing connected with them which is facilitated by the use of a globe.

These planets certainly may be said to move round the heavens, but it is not with the same regularity as the sun and moon. The two last always move in one direction, from west to east:

all the other planets move sometimes from west to east, sometimes from east to west; but much more of the former than the latter, so that they may be said to *progress* with occasional *retrogradations*. The end of each kind of motion and the beginning of the next is performed with such extreme slowness, that for several days together the planet does not seem to change its place among the stars at all, whence it is said to be *stationary*, which it is, as far as *visible* motion is concerned. In every instance the planet appears largest when it is retrograding most rapidly, half way between the two periods at which it is stationary. The times during which the several planets are retrograde, are about 22 days for Mercury, 41 days for Venus, from 60 to 80 days for Mars, 119 days for Jupiter, 137 days for Saturn, and 151 days for Uranus, varying a little on one side or the other, but not so much as to make it worth while to give extreme limits, except in the case of Mars. Thus, at the beginning of 1834, Saturn was progressing slowly at about 7 seconds (time) of right ascension in every day; by Jan. 20 he had become stationary, or practically so, the alteration of right ascension in 24 hours being under one-tenth of a second. Retrogradation then began to take place, which continued till the 7th of June, when the planet was stationary again, having retrograded 138 days. Two or three days at the beginning and end of the retrogradation may be considered as belonging to the stationary period, on account of the extreme smallness of the daily motion. But it ought to be remembered that the planet is never really stationary in the heavens: the moment it ceases to go forward among the stars, it begins to go back.

There is in the motions of *all* the planets a dependence upon that of the *sun*. Mercury and Venus never are at more than a certain distance from the sun: when they have receded to this distance, they begin to get nearer again. The greatest recess of Mercury from the sun varies at different times from 16¼° to 28¾°; that of Venus from 45° to 47¼°. Mars, Jupiter, Saturn, and Uranus get to all distances from the sun, even to actual opposition, or to 12^h difference of right ascension But there is still (except as to Mars) a dependence upon the solar motion, or, which is the same, upon the length of the year, distinctly perceptible. Mars began to retrograde Nov. 24, 1834; and after becoming progressive again, did not begin to retrograde till December 29, 1836, after more than two years had elapsed. But Jupiter, Saturn, and Uranus have all of them little more than a year between the commencements of two retrogradations.

The motions of the planets being thus oscillatory, it will be more desirable to state the periods in which they come again into the position they had at first with respect to the sun, than to give the times of sidereal revolution round the earth. Mercury, always close to the sun, does not, nevertheless, complete a cycle of positions through which, or nearly through which, it goes again, in less than 13 years and 3 days, or 2 days if there be 4 leap-years in the period. At the end of this interval the declination of the planet, its distance from the earth and from the sun, and the difference between the sun's right ascension and its own (and consequently the time of coming on the meridian), are nearly as at the beginning, and alter nearly as they altered before. Let us take, for instance, the declination of the planet and the time of coming on the meridian at Greenwich, counting astronomically (page 71).

	Decl.	Merid. Transit.		Decl.	Merid. Transit.
Jan. 1, 1834...	21° 32′	22^h 28^m·9	July 7, 1834...	17° 18′	1^h 54^m·2
Jan. 4, 1847...	21 49	22 29 ·1	July 10, 1847 ..	16 22	1 54 ·4
Feb. 7, 1835...	13 49	0 53 ·3	Sept. 9, 1835 ..	3 19	0 29 ·3
Feb. 10, 1848...	12 43	0 53 ·1	Sept. 11,* 1848..	2 9	0 28 ·1

There is a similar period for Venus of 8 *common* years exactly, of which the following are specimens:—

	Decl.	Merid. Transit.		Decl.	Merid. Transit.
Jan. 3, 1834 ..	23° 12′	22^h 59^m·6	July 7, 1834 ..	17° 43′	2^h 15^m·8
Jan. 1, 1842 ..	23 7	22 59 ·2	July 5, 1842 ..	18 16	2 16 ·2
March 15, 1836,	12 52	2 28 ·2	Nov. 21, 1836 ..	5 14	21 7 ·7
March 13, 1844,	12 11	2 28 ·9	Nov. 19, 1844 ..	4 34	21 8 ·3

The similar period† for Mars is 15 years and 18 days. For Jupiter 83 years is a very near cycle of the same kind, but 12 years and 5 days is tolerably exact. For Saturn we have 59 years and 2 days; for Uranus 84 years. We try the shorter period for Jupiter in the following instances :—

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* There are *four* 29ths of February in this interval, *three* in the others.

† All these, be it remembered, are not the periods in which the planets revolve round the heavens, but repetitions of them. For instance, when Mercury has just repeated the circuit of the earth's visible heaven, he is not in the same position with respect to the sun as at the beginning. So, in a watch, the cycle of relative positions of the minute and hour hand is not repeated in every hour, but in every 12 hours.

	Decl.	Merid. Transit.		Decl.	Merid. Transit.
Jan. 1, 1834...	8° 50′	$6^h\ 54^m\cdot0$	July 1, 1834 ..	19° 29′	$21^h\ 15^m\cdot0$
Jan. 6, 1846...	10 45	6 53 ·5	July 6, 1846 ..	20 31	21 15 ·9
May 12, 1835...	22 23	1 41 ·4	Dec. 17, 1835 ..	22 51	13 12 ·2
May 17, 1847...	22 54	1 42 ·4	Dec. 22, 1847 ..	22 28	13 11 ·9

The following (from Baily's *Tables and Formulæ*) is a stricter account of the retrogradations of the several planets :—

Planet.	Arc through which it retrogrades.	Duration of retrogradation.	Distance from Sun at which it begins.	Distance from Sun at which it ends.
Mercury.	9° 22′ to 15° 44′	$21^d\ 12^h$ to $23^d\ 12^h$	15° 24′ to 18° 39′	14° 49′ to 20° 51′
Venus...	14 35 17 12	40 21 43 12	27 40 29 41	27 40 29 41
Mars....	10 6 19 35	60 18 80 15	128 44 136 37	128 44 136 37
Jupiter..	9 51 9 59	116 18 122 12	113 35 116 42	113 35 116 42
Saturn ..	6 41 6 55	138 18 135 9	107 25 110 46	107 25 110 46
Uranus..	3° 36′	151^d	103° 30′	103° 30′

The planets, like the stars, always appear at one distance from the spectator, and evince their changes of distance to the reason only by alternately becoming larger and smaller. Thus the diameter of Mercury (meaning the apparent arc of the heavens which it occupies) varies from 7″ to 12″; of Venus, from 17″ to 61″; of Mars, from 6″ to 18″; of Jupiter, from 37″ to 46″; that of Saturn is about 16″; that of Uranus 4″.

On putting together the motion in the heavens with such approach to and recession from the earth as will serve to bring about the observed changes in the diameters, it is found that all the planets describe looped curves (such as that in page 17), relatively to the earth at rest. These looped curves do not return unto themselves exactly, but only nearly, in the several periods of restitution above mentioned. Though I do not enter into the question of the *actual* motions of our system, but confine myself entirely to appearances, yet I introduced the instance of compound motion given in page 17, that the attentive reader might be able to satisfy his own mind of the fact that the doctrine of Copernicus is a sufficient explanation of the things which are actually seen. By reading the description of that example, it may be seen that the moving point there supposed appears to become stationary when it has got so far down one side of the loop that the line of motion passes through O; that it is stationary again at a similar point on the other side of the loop; and that the motion of retrogradation is performed in the interval. The numbers and relative positions of the several loops may be collected from the almanac by looking at the retrogradations.

In the motion of the planets through their looped curves there is observed a remarkable connexion with the sun. Mercury and Venus are always at the very bottom of their loops (or nearest to the earth) when they are in conjunction with the sun, or in the same longitude; but Mars, Jupiter, Saturn, and Uranus are at the bottom of their loops when they are in opposition to the sun, or at the opposite part of the heavens. Look in the Nautical Almanac for 1846, and it will appear that the diameter of Jupiter is greatest at the beginning of December: look at the opposite part of the page, and it will be seen that he then passes the meridian at midnight, or is opposite to the sun. But in the same year the diameter of Venus is greatest at the end of February, at which time she is on the meridian with the sun. It is also found that all the planets have their least diameters when they are in conjunction with the sun, it being remembered that Mercury and Venus have *two* conjunctions with the sun, one while they progress, another while they are retrograding; while all the other planets have a conjunction in their progress, and an opposition while they are retrograding.

The apparent path of the planets is not exactly as in the example of page 17, for they do not retrograde precisely over the same arc on which they advanced. In fact, a retrogradation and its two subsequent progressions make on the globe a sort of wave in the case of Mercury, and an irregular loop in that of the other planets. The reader must make this out for himself by laying down the path of a planet, from its daily positions in the almanac, from some time before till some time after the retrogradation. From this it appears that the curve is not all in one plane: if a wire were wound round a cylinder, and then taken off and drawn out without destroying its looped character, and also without allowing the convolutions to meet, it might give some idea of the real path of one of the more distant planets, relatively to the earth. But on this it would be difficult to convey a satisfactory idea to any one who is unused to geometry.

Having thus given a general notion of the apparent motions of the planetary bodies among the stars, I can only leave the reader to deal with any planet, when its place is laid down for the time being from the almanac, precisely as he would do with a star, in any problem which is to be solved.

I have not particularly mentioned the four small planets, which, never being visible to the naked eye, are but of little interest to the ordinary user of a globe. Lying between Mars and Jupiter, their orbits round the earth present characteristics intermediate between those of Mars and Jupiter.

CHAPTER XI.

On the perennial globe, movable planisphere, and globe-atlas.

THE precession of the equinoxes, as described in page 73, amounts only to about 50″ in the year, or a degree in seventy years, nearly. Its effect is most clearly expressed by the supposition that the stars revolve slowly round the pole of the ecliptic in the progressive direction, or from west to east, completing a revolution in 26,000 years. This motion is not in truth perfectly uniform; but the supposition of such a rotation will serve well enough to describe the phenomena of the 2500 years of astronomical history: particularly if the average rate for that period be taken, instead of the actual present rate.

This precession is so slow that it is not necessary to make any representation of it on common globes. Those which I have been describing, and which are made accurate for the year 1850, will not be rendered by the precession unfit for common use even in 1900. But any globe, unprovided with a rotation about the pole of the ecliptic, and fit for use in our time, must be sensibly unfit to represent the heavens of Hipparchus or Ptolemy. For it must be remembered that while the stars gradually revolve about the pole of the ecliptic, the pole of the equator does not revolve with them, so that every star which is distant by about 23° from the pole of the ecliptic, will in its turn approach close to the pole of the heavens, and continue for a long time to be a pole-star.

The *perennial globe* * is a contrivance in which there is a motion of the stars about the pole of the ecliptic, and also one about the pole of the equator, so that all the diurnal phenomena can be represented for any epoch, however distant from our own, past or future. The globe is first placed in a brazen circle, exactly resembling the brazen meridian of a common globe: in this circle, it does not turn round the poles of the heavens, but round the poles (A, *a*) of the ecliptic. This first brazen circle, being always the *solsticial colure*, may be called the *brazen colure:* motion of the globe on its *colure-pivots* gives the motion of the stars in precession; that is, alters all their longitudes, without altering their latitudes. The brazen colure is not inserted into a wooden horizon, but into a larger brazen circle of the same kind, inside which it turns; care being taken that the colure-pivots (A, *a*), on which the globe turns, shall be distant from the meridian-pivots (B, *b*) by the obliquity of the ecliptic, or 23½°. This outer brass circle is the meridian, and it is inserted as usual into a wooden horizon. There is stiff friction at A and *a*, so that when the brazen colure is made to revolve round the axis B*b*, the globe moves with it; and this gives the diurnal motion. In the figure the point C (under B) represents the north pole of the heavens: let the globe move from west to east without the colure, and presently the point D will take the place of C: the effect upon the positions of the stars, with reference to the pole of the heavens, is that of a long period of precession.

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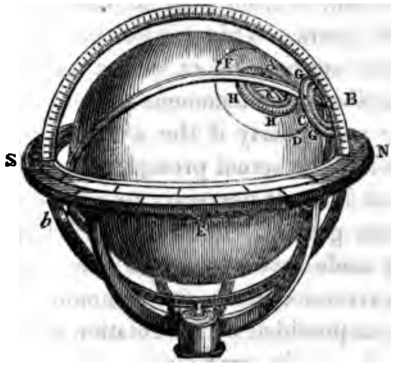
* This is the contrivance of John Taylor, Esq., of Liverpool. Senex, an old globe-maker of notoriety, used to make globes on a similar principle, but different in their details. These are described in Benjamin Martin's work on the Use of the Globes, chapter ix., and by Costard in page 132 of his History of Astronomy. As far as I can judge from these descriptions, which are not very intelligible, Mr. Taylor's plan is better than that of Senex.



The equator, hour circles, and parallels engraved upon the globe, are useless, except when the globe is rectified for the year 1850, or near it: that is, except when the point which is now the pole of the heavens is brought under B. To provide a substitute, a circle G is screwed to the brazen colure, and turns with it; on this circle are placed hours and degrees of right ascension, days of the month, and a solar zodiac. A movable hour-circle is added, which turns both with the brazen colure and independently of it; being in fact what has been hitherto called the brazen parallel. But the ecliptic painted on the globe is permanent, though the dates and longitudes laid down upon it are useless, except for the present time.

At the pole of the ecliptic are two circles (H and K) which move with the globe, and also independently of it. The larger one shows a succession of dates before and after the Christian era, with a cycle of the days of the months, and a solar zodiac: the smaller one has also a succession of dates, and two points marked P and A. The larger one is to set the globe in its proper position; the smaller one is to ascertain the place of the sun's apogee. Call these the *ecliptic parallels.*

To set the globe in its proper position for the year 1850:—Make the graduated edges of the brazen colure and the brazen meridian coincide. Turn the globe until the painted solsticial colure coincides with the brazen colure, and the intersection of the painted colures on the globe is under B, the pivot of the brazen colure. Turn both the ecliptic parallels until the date 1850 on both is on the brazen colure between the two poles. Then, when the brazen meridian is elevated for the latitude of the place, the globe is in the position required, for any moment at which the summer solstice is on the meridian. And the point P on the smaller ecliptic circle points at January 1 on the larger, showing the time of the year at which the sun is in perigee, or nearest to the earth. Any amount of diurnal motion must now be given by moving the brazen colure and the globe with it. The globe itself must never be touched, except to set the heavens for another date.

To find the position of the heavens at any other date:—Move the *larger ecliptic parallel* until the given date is on the painted colure, looking towards the painted pole. Then move the *globe,* until A.D. 1850 on the larger ecliptic parallel is on the graduated edge of the brazen colure. The globe is then in position, and diurnal motion, as before, must be given by means of the brazen colure. To find the time of the sun's perigee, bring the date in question on the smaller ecliptic parallel to the brazen colure, between the poles, and the point P will be opposite to the time of the year required on the larger ecliptic parallel.

The sun's perigee moves among the stars only 12″ in a year, from west to east; but with the motion of the stars it moves altogether 62″ in a year. In reading of these several motions, some confusion may arise to the beginner who does not remember that relative motions always admit of several descriptions. Thus in the present instance we fix the equinox, and allow the stars to move; in which case the solar perigee must take the motion of the stars generally, conjointly with its own motion among the stars. But say that the stars are fixed, and the equinox recedes; then the perigee, though moving only with its own motion among the stars, still increases its distance from the equinox by 62″ yearly; since the equinox moves back 50″, and the perigee moves forward 12″. In the globe we are describing, the stars are made to move while the equinox remains fixed: for the motion of precession is that of the globe without the colure, and a fixed colure implies a fixed equinox.

It is probable that those who use this perennial globe will be those who have more than usual taste for astronomy, and such knowledge of the subject as would render further details unnecessary for them. Nevertheless, as the diagram given above may facilitate the attainment of a just idea of precession by those who will not see the globe which it represents, I have deferred to this part of the work some matters connected with the effect of the changes in the pole of the heavens.

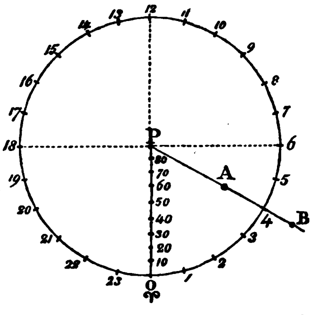
The sun, when on the meridian, is eastward of its position when on the meridian the day before; accordingly, every star rises earlier on each day than on the day before. If we suppose a star to rise with the sun on (say) the 1st of June, it will then be wholly invisible on that day, being made so by the sun's rays. The next day it will rise a little before the sun, being still invisible all day, since at its very rising the sun is almost on the horizon. This will go on for some time, until at last the star has gained so much upon the sun, that when it rises the eastern part of the heaven is dark enough for it to be just visible. But at first this will only happen for a very short time: for sunlight is close at hand, and the star will be lost in the sun's rays after being a very short time above the horizon. This getting up of the star early enough to be seen for a short time before sunrise extinguishes it, is called the *heliacal rising*. As time goes on, the star rises more and more before the sun, becoming visible longer and longer before sunlight, until at length it rises at midnight. In process of time it rises at sunset, or rather a little after sunset, so as to be invisible for a short time after rising, until the sunlight has disappeared. In this case it sets a little before sunrise, so that at setting it is lost to view. After this more and more of its appearance is destroyed by the sunlight, so that at last it has come to the meridian before the sun is sufficiently down for it to be visible. At length it is only just visible when about to set; and this is the *heliacal setting.* It is then completely lost for many days, and only becomes visible at the next heliacal rising; so that, in fact, the heliacal rising and setting of a star mean the rising and setting which take place when the star is so near the sun, on the west or east, that nothing but just the rising or the setting is visible. The heliacal setting comes just before the period of total disappearance, and the heliacal rising just after it. When the star rises or sets at exactly sunrise, it was said to rise or set *cosmically,* when it rises or sets exactly at sunset, *acronychally.*

The heliacal rising or setting of a star is a phenomenon depending on the brilliancy of the star, its place in the heavens, the general climate in which it is observed, the accidental climate of each particular year, and even on the optical capacity of the observer. Nevertheless it was at one time of considerable importance. In a rude country shepherds and husbandmen would know the coming seasons by the successive disappearance and reappearance of the several stars. The earlier Greek writings, accordingly, abound with, and contain indeed little more than, descriptions of the risings and settings of the stars through the year. The astronomers of the middle ages presumed that a star of the first magnitude can be seen at rising if the sun be 12° below the horizon; of the second magnitude if 13°; and so on, adding one more degree for each order of magnitude. But this is an exceedingly vague set of assumptions: and I hold the introduction of problems founded upon them into works on the *use* of the globes to be unnecessary.

The precession of the equinoxes will, in course of time, very much affect the positions of stars with respect to the equinox, and consequently the times of the year at which they rise heliacally. Let what supposition we please be made on the circumstances which determine those times in any one year, still in any one place it is clear that the heliacal rising must go through all times of the year in a complete revolution of the equinoxes; that is, in 26,000 years. The effect must be about a day in 70 years; that is, at the end of 70 years each star must rise heliacally a day later than at the beginning; at least in one period of seventy years with another. This gives a rough power of verifying chronological facts, as in the following instance:—Hesiod distinctly says that Arcturus rose at sunset sixty days after the winter solstice, or as we should say, about February 19. Assuming that Hesiod lived B.C. 900, in latitude 38°, or thereabouts; set the globe for that time and latitude, and bring Arcturus to the eastern horizon. The point of the ecliptic which is setting is that which is *now* marked March 30. To find where the winter solstice was then, look where the brazen colure cuts the ecliptic next before March 30, and we find it at what is now marked January 29. The interval is exactly sixty days, though probably the fact of agreement within a single day is an accidental coincidence. From the globe it will also appear that in the time of Hesiod what we now call the pole-star was 15° distant from the pole, near which there was then no star of any great magnitude.

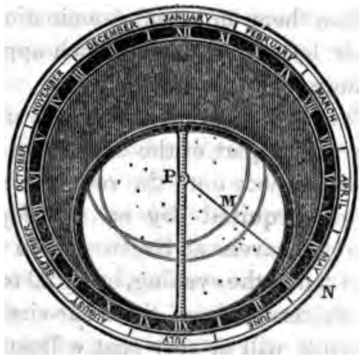
I now proceed to the description of the *movable planisphere*, an instrument which is intended to supply the place of a globe to a certain extent. Any representation of the globe upon a plane was called a planisphere, though the term is somewhat out of use. The instruments in question are of two kinds: in the older ones there are two movable parts and one fixed part; in those which I proceed to describe, there is only one movable part.

Any map of the stars is a sufficient mode of finding them when a rule is arranged by which every point of the map belongs to one right ascension and declination, and only to one: for then, a right ascension and declination being given, it can be found whether or no there is a star at the point appropriated to that right ascension and declination. For example, let the point P represent the pole, and let the circle represent the equator; the numerals being hours of right ascensions. Let the radius P 0 be divided into 90 equal parts, and let each of these parts represent one degree of declination. It is plain then that we can find a place for every northern star: A, for example, is in 4^h of right ascension and 30° of north declination. There will be much distortion of the relative positions of the stars, which is of no conse-



quence for any purpose in reference to which right ascensions and declinations are the only requisites. We may even carry our distortion still further, by carrying on beyond the circle for southern stars: thus B may represent a star in 4^h of right ascension and 20° of south declination. At this rate the south pole would be magnified and distorted into the whole of another circle, having a radius of twice P 0. To carry matters to this extent might be unadvisable; but for all the southern parts of the heavens that can be seen at Greenwich there is no unreasonable amount of distortion.

Now suppose that on such a planisphere a position of the horizon at Greenwich is marked out, which will be a sort of unsymmetrical oval curve, and may pass through 6 and 18. Let this horizon be cut out of pasteboard, leaving a bar across it for the meridian, and let the bar turn on a pivot at P, so as to show different parts of the planisphere in different positions.



Then, by moving the meridian-bar round its pivot P, and the horizon with it, the opening which is seen on the planisphere contains a portion of the heavens which is visible at Greenwich at some one time. And however the opening may be varied, by making the movable slip, or *horizon-piece*, revolve, the same thing is true: some one collection of stars visible at some one and the same time is seen through the opening; all that is below the horizon at that one time being hidden. And what is seen at Greenwich represents with sufficient accuracy what is seen in any part of Britain. We must now describe the manner of setting the planisphere for any given time.

Round the outer edge of the horizon-piece, and of course revolving with it, is a circle marked with hours and minutes, one side giving from 0 to 12^h of the forenoon, the other the same of the afternoon. Adjacent to this circle, and on the border of the fixed planisphere, is another circle, on which are marked all the days of the year. This circle is immovably related to the ecliptic on the planisphere in the following manner:—a line P M drawn through the pole to the border-circle at N will show at N the same day as that which is marked on the ecliptic at M; thus if we see May 21 at M, we shall also see May 21 at N. The circle at the edge of the horizon-piece may be called the *hour-circle,* and that at the edge of the planisphere the *day-circle.* True solar, or sun-dial, time must be used.

Round the border of the horizon are placed the points of the compass. And it will be seen on examination, that when the planisphere is laid on the table with the southern end of the horizon-piece nearest to the spectator, the western edge is on his right hand and the eastern edge on his left; against all rule. The meaning of this is, that it was intended the spectator should hold the planisphere above him, and look at it from underneath, in which case the above positions will be reversed. It is not likely, however, that many persons will choose this awkward mode of examination: those who prefer to lay the planisphere before them, in actual examination of the heavens, must look on their left for the stars which appear on their right in the planisphere, and *vice versâ.*

There is but one rule for the use of this planisphere. To find the visible part of the heavens at any hour of any day, turn the horizon-piece until the required *hour* on the *hour-circle* is opposite to the required *day* on the *day-circle.* Thus, to exhibit the visible heavens at Greenwich on the 15th of May at 20 minutes past ten in the evening, bring 20 minutes past ten on the afternoon, or western, side of the hour-circle, to May 15 on the day-circle. Then it will be seen that η Bootis, η Ursæ Majoris, and ι Draconis have just passed the meridian; that α Bootis and θ Centauri will soon be on the meridian; that α Hydræ, Procyon, and β Aurigæ will soon set; that α Aquilæ and α Scorpii have not long risen; and that Spica Virginis has passed the meridian by about half an hour.

When the hour-circle is in any one position, a look round it shows the different hours which that position happens in on the different days in the year. Thus, opposite to four in the afternoon (the horizon-piece not having been moved since it was set for the above question) we see August 18, which means that on August 18, at four in the afternoon, the part of the heavens which is above the horizon is that which is also above the horizon at 20 minutes past ten in the evening on the 15th of May.

When will Regulus, or α Leonis, rise, come to the meridian, and set, on the 17th of August? Bring α Leonis to the eastern side of the horizon, or rather bring the eastern side of the horizon to α Leonis: opposite to August 17 on the day-circle is seen a quarter past five in the morning on the hour-circle; this is the time of rising. Bring the meridian to α Leonis: opposite August 17 on the day-circle is seen a quarter past twelve in the afternoon; this is the time at which α Leonis is on the meridian. Bring the western edge of the horizon to α Leonis: opposite to August 17 is seen a quarter past seven in the evening.

The moon is in right ascension $4^h\ 28^m$, and in declination 17° north: what star is she near to? Turn $4^h\ 28^m$ into degrees, which gives 67°. Bring the graduated edge of the meridian to 67° on the equator, and then look northward 17° on the edge of the meridian. It appears that the moon is then very close to, but a little above, the bright star of Taurus, Aldebaran.

Such questions as these, and many others, might be multiplied with little profit: for a person who can use the globes will readily see that he has before him a species of instrument which, so far as it can be used, has only this difference between it and the globe, that in the former the horizon and meridian are moved to the stars, and in the latter the stars are moved to the horizon and meridian. The planisphere is more portable than the globe, and has advantages in all problems in which the meridian, the horizon, and the time of happening, any or all, are the principal things: and most particularly in determining the different solar times at which sidereal phenomena happen at different times of the year. But in everything which concerns the zenith, or altitudes above the horizon, or distances of bodies from one another, or close resemblance to apparent configuration, the planisphere is of no use at all. There is a reality about the globe which the planisphere cannot imitate: in fact, the latter is a map, with some apparatus conjoined. It is also constructed only to suit one latitude: though, with different horizon-pieces to the same planisphere, any number of different latitudes might be provided for. Still less, of course, can it suit different positions of the pole among the stars, or supply the place of the perennial globe: and here again, a planisphere constructed for the time of Hipparchus and for the latitude intermediate between those of Athens and Alexandria, would sufficiently serve the purposes of the scholar who wants to read ancient astronomical writings with the power of testing the accuracy of the statements.

A terrestrial planisphere should be constructed as follows:—It should extend only to the equator, and the pivot of the hour-circle should be at the pole. The opening should be circular, and should just show the equator all round. The northern hemisphere being first drawn upon the planisphere, the southern hemisphere should be drawn over it, *inverted*, in such a manner that every part of the northern hemisphere should have its antipodes upon it. The notions of most persons upon the parts of the earth which come opposite to one another are exceedingly vague, and just ideas of geographical position would be easily attained by the execution of several projects of this sort. First, both northern and southern hemispheres should be projected upon the equator, so that every place might show its own antipodes, or the place which is diametrically opposite. Secondly, two hemispheres should be projected upon one meridian, in such manner that each place should show what part of the earth is opposite in longitude, but of the same latitude. Thirdly, the two hemispheres should be projected upon the equator, so that places of the same longitude, but of opposite latitudes, might come together.

In the terrestrial planisphere above mentioned, instead of a day-circle at the boundary of the planisphere, there might be another hour-circle, in such manner that, by comparison of the movable and fixed hour-circles, it might immediately be seen what hour it is at any one place, when it is noon, or any other given hour, at another.

Every map of the stars is accompanied by distortion, or alteration of the relative places of the stars. No portion of the sphere can be unrolled upon a plane without something either of rumpling or tearing. But for tolerably large portions of the sphere, there is so little of either, that a globe is made by pasting gores and zones of paper, which have been previously engraved in the usual way, upon the surface of a sphere. If then zones and gores were printed in sheets, an atlas might be made of them; and if several of them were put together on one sheet, their edges would not accurately join, as on the globe, but only very nearly. Such an atlas is published by Mr. Malby, from the pieces of a 36-inch globe, which has been made to serve the purpose of either globe or atlas. But the truth is, that those who want such a scale, generally have to examine a small portion of the earth or heavens by itself, and thus an atlas may be more convenient. By preserving the zones and gores of the sphere in a plane atlas, angles are altered, but not very much; while distances are almost absolutely preserved. Each atlas is complete in 21 sheets, and is reduced to the year 1825. The stars and nebulæ are laid down to the same extent* as in the large maps published by the Society for the Diffusion of Knowledge; and the magnitudes are taken from Harding, and also quoted from Argelander, whenever the two differ. It must be noted that the magnitudes given by Argelander (page 52) have been adopted at Greenwich: they differ from Piazzi's in 877 instances, but from Harding's in only 612.

Globes of this size may be made useful for teaching in large classes; at least if mounted† with an iron meridian, on which the divisions are legibly painted, and if the names of kingdoms, principal cities, &c. are made sufficiently clear. On a 36-inch terrestrial globe, an inch represents little more than 220 miles, and the length of a mile is perfectly visible.

After learning how to use a globe, and how to interpret the Nautical Almanac or any other Ephemeris, the student is well prepared to read works on astronomy, as distinguished from those on the use of the globes; meaning works which enter on the real motions from which the appearances treated of in this work are derived. Nothing can be more convincing than the evidence for the truth of the modern systems: but nothing can be more vague and unsatisfactory than that evidence as it is frequently presented. Not that the works in which it is presented are in fault, but the mind of the reader, who has, generally speaking, little knowledge of the apparent motions, and none whatever of the effect of compounding different notions. Astronomy requires to be learnt in a sound and accurate, though only in a popular, manner; accompanied by a close attention to the old maxim of good sense—one thing at a time.

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* Stars from Piazzi, Bradley, Hevelius, Mayer, Lacaille, and Johnson: nebulæ from W. Herschel, J. Herschel, and Dunlop.

† Mr. Malby prepares them in this manner, and also with an apparatus for hanging them from the ceiling of a school-room or library, and letting them down at pleasure; so that they may not be in the way except when wanted.

APPENDIX I.

A Table of Versed Sines to the Diameter 200,000, the use of which is explained in pages 29—32.

		V.			V.			V.
0° 0′	180° 0′	0	7° 0′	173° 0′	745	14° 0′	166° 0′	2970
10	50	0	10	50	781	10	50	3041
20	40	2	20	40	818	20	40	3113
30	30	4	30	30	856	30	30	3185
40	20	7	40	20	894	40	20	3258
50	10	11	50	10	933	50	10	3333
1° 0	179° 0	15	8° 0	172° 0	973	15° 0	165° 0	3407
10	50	21	10	50	1014	10	50	3483
20	40	27	20	40	1056	20	40	3560
30	30	34	30	30	1098	30	30	3637
40	20	42	40	20	1142	40	20	3715
50	10	51	50	10	1186	50	10	3794
2° 0	178° 0	61	9° 0	171° 0	1231	16° 0	164° 0	3874
10	50	72	10	50	1277	10	50	3954
20	40	83	20	40	1324	20	40	4036
30	30	95	30	30	1371	30	30	4118
40	20	108	40	20	1420	40	20	4201
50	10	122	50	10	1469	50	10	4285
3° 0	177° 0	137	10° 0	170° 0	1519	17° 0	163° 0	4370
10	50	153	10	50	1570	10	50	4455
20	40	169	20	40	1622	20	40	4541
30	30	187	30	30	1675	30	30	4628
40	20	205	40	20	1728	40	20	4716
50	10	224	50	10	1782	50	10	4805
4° 0	176° 0	244	11° 0	169° 0	1837	18° 0	162° 0	4894
10	50	264	10	50	1893	10	50	4985
20	40	286	20	40	1950	20	40	5076
30	30	308	30	30	2008	30	30	5168
40	20	332	40	20	2066	40	20	5260
50	10	356	50	10	2125	50	10	5354
5° 0	175° 0	381	12° 0	168° 0	2185	19° 0	161° 0	5448
10	50	406	10	50	2246	10	50	5543
20	40	433	20	40	2308	20	40	5639
30	30	460	30	30	2370	30	30	5736
40	20	489	40	20	2434	40	20	5833
50	10	518	50	10	2498	50	10	5932
6° 0	174° 0	548	13° 0	167° 0	2563	20° 0	160° 0	6031
10	50	579	10	50	2629	10	50	6131
20	40	610	20	40	2696	20	40	6231
30	30	643	30	30	2763	30	30	6333
40	20	676	40	20	2831	40	20	6435
50	10	710	50	10	2900	50	10	6538

A Table of Versed Sines—*continued.*

		V.			V.			V.
21° 0′	159° 0′	6642	31° 0′	149° 0′	14283	41° 0′	139° 0′	24529
10	50	6747	10	50	14433	10	50	24720
20	40	6852	20	40	14584	20	40	24912
30	30	6958	30	30	14736	30	30	25104
40	20	7065	40	20	14888	40	20	25297
50	10	7173	50	10	15041	50	10	25491
22° 0	158° 0	7282	32° 0	148° 0	15195	42° 0	138° 0	25686
10	50	7391	10	50	15350	10	50	25880
20	40	7501	20	40	15505	20	40	26076
30	30	7612	30	30	15661	30	30	26272
40	20	7724	40	20	15818	40	20	26469
50	10	7836	50	10	15975	50	10	26667
23° 0	157° 0	7950	33° 0	147° 0	16133	43° 0	137° 0	26865
10	50	8064	10	50	16292	10	50	27063
20	40	8178	20	40	16451	20	40	27263
30	30	8294	30	30	16611	30	30	27463
40	20	8410	40	20	16772	40	20	27663
50	10	8528	50	10	16934	50	10	27864
24° 0	156° 0	8645	34° 0	146° 0	17096	44° 0	136° 0	28066
10	50	8764	10	50	17259	10	50	28268
20	40	8884	20	40	17423	20	40	28471
30	30	9004	30	30	17587	30	30	28675
40	20	9125	40	20	17752	40	20	28879
50	10	9247	50	10	17918	50	10	29084
25° 0	155° 0	9369	35° 0	145° 0	18085	45° 0	135° 0	29289
10	50	9493	10	50	18252	10	50	29495
20	40	9617	20	40	18420	20	40	29702
30	30	9741	30	30	18588	30	30	29909
40	20	9867	40	20	18758	40	20	30117
50	10	9993	50	10	18928	50	10	30325
26° 0	154° 0	10121	36° 0	144° 0	19098	46° 0	134° 0	30534
10	50	10248	10	50	19270	10	50	30744
20	40	10377	20	40	19442	20	40	30954
30	30	10507	30	30	19614	30	30	31165
40	20	10637	40	20	19788	40	20	31376
50	10	10768	50	10	19962	50	10	31588
27° 0	153° 0	10899	37° 0	143° 0	20136	47° 0	133° 0	31800
10	50	11032	10	50	20312	10	50	32013
20	40	11165	20	40	20488	20	40	32227
30	30	11299	30	30	20665	30	30	32441
40	20	11434	40	20	20842	40	20	32656
50	10	11569	50	10	21020	50	10	32871
28° 0	152° 0	11705	38° 0	142° 0	21199	48° 0	132° 0	33087
10	50	11842	10	50	21378	10	50	33303
20	40	11980	20	40	21558	20	40	33520
30	30	12118	30	30	21739	30	30	33738
40	20	12257	40	20	21921	40	20	33956
50	10	12397	50	10	22103	50	10	34175
29° 0	151° 0	12538	39° 0	141° 0	22285	49° 0	131° 0	34394
10	50	12679	10	50	22469	10	50	34614
20	40	12822	20	40	22653	20	40	34834
30	30	12964	30	30	22838	30	30	35055
40	20	13108	40	20	23023	40	20	35277
50	10	13252	50	10	23209	50	10	35499
30° 0	150° 0	13397	40° 0	140° 0	23396	50° 0	130° 0	35721
10	50	13543	10	50	23583	10	50	35944
20	40	13690	20	40	23771	20	40	36168
30	30	13837	30	30	23959	30	30	36392
40	20	13985	40	20	24149	40	20	36617
50	10	14134	50	10	24339	50	10	36842

A Table of Versed Sines—*continued.*

		V.			V.			V.
51° 0′	129° 0′	37068	61° 0′	119° 0′	51519	71° 0′	109° 0′	67443
10	50	37294	10	50	51774	10	50	67718
20	40	37521	20	40	52029	20	40	67994
30	30	37749	30	30	52284	30	30	68270
40	20	37976	40	20	52540	40	20	68546
50	10	38205	50	10	52796	50	10	68822
52° 0	128° 0	38434	62° 0	118° 0	53053	72° 0	108° 0	69098
10	50	38663	10	50	53310	10	50	69375
20	40	38893	20	40	53567	20	40	69652
30	30	39124	30	30	53825	30	30	69929
40	20	39355	40	20	54083	40	20	70207
50	10	39586	50	10	54342	50	10	70485
53° 0	127° 0	39819	63° 0	117° 0	54601	73° 0	107° 0	70763
10	50	40051	10	50	54860	10	50	71041
20	40	40284	20	40	55120	20	40	71320
30	30	40518	30	30	55380	30	30	71598
40	20	40752	40	20	55641	40	20	71878
50	10	40986	50	10	55902	50	10	72157
54° 0	126° 0	41221	64° 0	116° 0	56163	74° 0	106° 0	72436
10	50	41457	10	50	56425	10	50	72716
20	40	41693	20	40	56687	20	40	72996
30	30	41930	30	30	56949	30	30	73276
40	20	42167	40	20	57212	40	20	73557
50	10	42404	50	10	57475	50	10	73837
55° 0	125° 0	42642	65° 0	115° 0	57738	75° 0	105° 0	74118
10	50	42881	10	50	58002	10	50	74399
20	40	43120	20	40	58266	20	40	74680
30	30	43359	30	30	58531	30	30	74962
40	20	43599	40	20	58796	40	20	75244
50	10	43840	50	10	59061	50	10	75526
56° 0	124° 0	44081	66° 0	114° 0	59326	76° 0	104° 0	75808
10	50	44322	10	50	59592	10	50	76090
20	40	44564	20	40	59859	20	40	76373
30	30	44806	30	30	60125	30	30	76655
40	20	45049	40	20	60392	40	20	76938
50	10	45292	50	10	60659	50	10	77222
57° 0	123° 0	45536	67° 0	113° 0	60927	77° 0	103° 0	77505
10	50	45780	10	50	61195	10	50	77788
20	40	46025	20	40	61463	20	40	78072
30	30	46270	30	30	61732	30	30	78356
40	20	46516	40	20	62001	40	20	78640
50	10	46762	50	10	62270	50	10	78924
58° 0	122° 0	47008	68° 0	112° 0	62539	78° 0	102° 0	79209
10	50	47255	10	50	62809	10	50	79493
20	40	47502	20	40	63079	20	40	79778
30	30	47750	30	30	63350	30	30	80063
40	20	47998	40	20	63621	40	20	80348
50	10	48247	50	10	63892	50	10	80634
59° 0	121° 0	48496	69° 0	111° 0	64163	79° 0	101° 0	80919
10	50	48746	10	50	64435	10	50	81205
20	40	48996	20	40	64707	20	40	81491
30	30	49246	30	30	64979	30	30	81776
40	20	49497	40	20	65252	40	20	82063
50	10	49748	50	10	65525	50	10	82349
60° 0	120° 0	50000	70° 0	110° 0	65798	80° 0	100° 0	82635
10	50	50252	10	50	66071	10	50	82922
20	40	50505	20	40	66345	20	40	83208
30	30	50758	30	30	66619	30	30	83495
40	20	51011	40	20	66894	40	20	83782
50	10	51265	50	10	67168	50	10	84069

A Table of Versed Sines—*continued.*

		V.			V.			V.
81° 0′	99° 0′	84357	84° 0′	96° 0′	89547	87° 0′	93° 0′	94766
10	50	84644	10	50	89836	10	50	95057
20	40	84931	20	40	90126	20	40	95347
30	30	85219	30	30	90415	30	30	95638
40	20	85507	40	20	90705	40	20	95929
50	10	85795	50	10	90995	50	10	96219
82° 0	98° 0	86083	85° 0	95° 0	91284	88° 0	92° 0	96510
10	50	86371	10	50	91574	10	50	96801
20	40	86659	20	40	91864	20	40	97092
30	30	86947	30	30	92154	30	30	97382
40	20	87236	40	20	92444	40	20	97673
50	10	87524	50	10	92734	50	10	97964
83° 0	97° 0	87813	86° 0	94° 0	93024	89° 0	91° 0	98255
10	50	88102	10	50	93315	10	50	98546
20	40	88391	20	40	93605	20	40	98836
30	30	88680	30	30	93895	30	30	99127
40	20	88969	40	20	94186	40	20	99418
50	10	89258	50	10	94476	50	10	99709
						90° 0	90° 0	100000

APPENDIX II.

Tables* for finding, within half an hour, the *Greenwich time* of new or full moon for any month of any year between B.C. 1000 and A.D. 2000.

Preliminaries.—In the first, third, and fourth tables; the days, hours, and minutes given, are accompanied by certain columns marked A and B. Remember that in every case, whatever is done with times taken out of these tables, be it addition or subtraction, is also done with their A's, and with their B's. But whenever a subtraction which is directed to be made cannot be made, add first $29^d\ 12^h\ 44^m$, if it be a time which is not large enough, and add 29 and 26 to the columns of A and B (as shown in the first line of Table I.). If it be an A or a B which is not large enough, add 360 to it, without touching anything else. This applies to all cases.

There are three steps in the operation, which it will be convenient to separate, because the first only has several cases. The first is, to find the mean new or full moon of the *January* of the given year. The second is, to find the mean new or full moon of the *required month.* The third is, by means of the A and B processes which have accompanied the preceding steps, to pass from the mean time to the true time: allowing for the moon's acceleration. The result is then obtained in *old style,* which must be altered into new style when necessary.

To find the mean new or full moon in January of any year.—First, for years *before* Christ. Take the given year (*a*); and find a year (*b*) in the eighteenth† century which, added to *one less than* the given year, makes a complete number (*c*) of centuries. From the time of new or full moon, whichever is wanted, opposite to (*b*) in Table III., subtract that opposite to (*c*) in Table IV. (attending to the *preliminaries* above mentioned): the result is the day of January required, with the hour and minute from noon (old style).

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* These tables are those given by Ferguson in his 'Select Mechanical Exercises.' I have added nothing, except Table V. for the effect of the acceleration of the moon's mean motion. Readers in general must use these tables without any idea of their construction. The mathematician will see that they apply to the time of *mean* new and full moon, the corrections depending on the anomalies of the sun and moon, which anomalies, and their changes, are given (in columns A and B) to degrees. This is enough, when all that is wanted is to be within half an hour: and I find that any alterations which could be made in Ferguson's numbers by help of more modern tables would not make more than two minutes' difference in the results. I have therefore not thought it worth while to amend them, except by supplying the correction for the acceleration. It must be noted that Ferguson has made the corrections additive, and put back all the mean moons accordingly. All other compendious attempts to find the new and full moons through any extensive period which I have seen inserted in books on the globes err as much as the *calendar moon,* from which Easter is deduced: frequently one day, sometimes two. The tables here given will very rarely indeed be wrong by 25 minutes, and most frequently by less than a quarter of an hour.

† That is, having 17 for the two first figures.

Secondly, for any year *after* Christ, but before 1700. Take a year (*b*) in the eighteenth century, of the same number as that proposed (*a*); and take the number (*c*) of centuries between the two. From the time of new or full moon, whichever is wanted, opposite to (*b*) in Table III., subtract that opposite to (*c*) in Table IV. (attending to the preliminaries): the result is the day of January required, &c. (old style).

Thirdly, when the year is between 1700 and 1800, both inclusive. There is no operation required; the answer being ready in Table III. (old style).

Fourthly, when the year is after 1800. Take a year (*b*) in the eighteenth century, of the same number as that proposed (*a*); and take the number (*c*) of centuries between the two. To the time of new or full moon, opposite to (*b*) in Table III., add that opposite to (*c*) in Table IV., &c.: the result is the day of January required, &c. (old style).

Let the result of this process be called (*d*).

To pass from the time (*d*) *of mean new or full moon in January to that of any other month of the same year.*—Count the number of lunations which intervene, allowing one for every month succeeding January: add (*e*) what is opposite to this number of lunations in Table I., and subtract the number of days (*f*) opposite to the beginning of the month in Table II. The result (*g*) is the day of the month required, with the hour and minute after noon.

To pass from the mean time of new or full moon to the true.—Having in the preceding steps dealt with each A and B precisely as with the time it accompanies, first, if the date be sufficiently distant from the present time to make it worth while, subtract the time belonging to that date in Table V. from (*g*) and the number under B in Table V. from the B obtained by the process. Then find out in Table VI. the numbers A and B obtained by the process, and add the times opposite to them to the time (*g*), or what is left of it. The result is the true day of new or full moon, with the hour and minute from noon, old style. But in the January or February of leap year add a day to the time finally found.

To turn old style into new, add as follows:—

From 1500 to March 1, 1700, add 10 days.
From March 1, 1700 to March 1, 1800, add 11* days.
„ March 1, 1800 to March 1, 1900, add 12 days.
„ March 1, 1900 to March 1, 2100, add 13 days.

EXAMPLE 1.—According to Mr. Baily's calculation,† an eclipse of the

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[*] But for English reckoning, keep old style till September 14, 1752.

[†] *Phil. Trans.*, 1811. This eclipse is said to have been predicted by Thales, and its appearance is recorded to have terminated a battle between the armies of Cyaxares and Alyattes in Asia Minor, by the fright it produced on both sides. Modern astronomy has settled the date of this battle, which was not accurately known, by detecting the only eclipse which could have been total in Asia Minor at any time in or near the lives of these kings.

sun took place B.C. 610, on the 30th of September, the middle of the eclipse happening when the sun was on the meridian in Persia. Now as an eclipse of the sun can only happen at the new moon, required the time of new moon in September, B.C. 610.

					A	B
(*a*) = 610	1791, Table III, gives	22^d	11^h	25^m	215	270
609	2400, Table IV. ,,	15	14	9	353*	291*
(*b*) = 1791	Subtract (*d*)	6	21	16	222	339
(*c*) = 2400	8, Table I. gives (*e*)	236	5	52	233	207
From Jan. to Sept. say 8 lunations.		243	3	8		
	Sept. Table II. (*f*)	243				
	Subtract	0	3	8		

Here we must retrace our steps, for 0 of September means the day before 1, or the last of August: months and lunations do not run so well together but what this will sometimes happen. Begin again at (*d*) and run on *nine* lunations instead of eight.

				A	B
(*d*)	6^d	21^h	16^m	222	339
9, Table I. (*e*)	265	18	36	262	232
	272	15	52	484	571
Sept. Table II. (*f*)	243			360	360
Subtract (*g*)	29	15	52	124	211
Table V. B.C. 610		2	51		6
Subtract	29	13	1	124	205
124, Table VI. (A)			40		
205, Table VI. (B)		5	57		
Add . .	29	19	38	True Greenwich time.	

Hence at Greenwich, the new moon of September, B.C. 610, took place 19^h 38^m after noon on the 29th, or at 38 minutes past seven on the morning of the 30th. Now Persia (or what went by that name) ranges from 3^h to $4\frac{3}{4}^h$ of longitude; let us take the mean $3\frac{7}{8}^h$, say 4^h. In 4^h east of Greenwich, the clock is 4^h faster than that of Greenwich, and 23^h 38^m after noon on the 29th, or 38 minutes past eleven, was the time of new moon on the meridian of 4^h east.

The reason why we use B.C. 609 instead of B.C. 610 is as follows:—In common reckoning the year 1 *after* Christ is immediately preceded by the year 1 before Christ. But a mathematical reckoning must have a year 0 between these two: according B.C. 1 is the astronomical 0, B.C. 2 is the astronomical B.C. 1, and so on; whence B.C. 610 is the astronomical B.C. 609. Observe also that the *common* B.C. 4, 8, 12, &c. are *not* leap years: the astronomical B.C. 0, 4, 8, 12, or the common B.C. 1, 5, 9, 13, &c. are leap years.

EXAMPLE 2.—Required the full moon of February, 1844, and the new moon of October, 1996.

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* Because these are too great add 360 to the lines above.

				A	B
1744 (III.)	16^{d}	10^{h}	29^{m}	210	198
100 (IV.)	4	8	11	3	255
Add .	20	18	40	213	453
1 (I.)	29	12	44	29	26
Add .	50	7	24	242	479
Febr. (II.)	31				
Subtract	19	7	24		

Here we must go back a lunation, for it is clear that the addition for new style will give the March moon.

	20	18	40	213	453
New style	12				
Add .	32	18	40	213	453
Febr. (II.)	31				360
Subtract	1	18	40	213	93
213 (VI. A)		6	30		
93 (VI. B)		19	32		
Add .	2	20	42		
For leap year	1				
Add .	3	20	42		

Answer, Feb. 3, at 20^{h} 42^{m} after noon;
or Feb. 4, at 8 42 in the morning.
Almanac: Feb. 4, at 8 43 in the morning.

Error, only one minute.

				A	B
1796 (III.)	26^{d}	8^{h}	56^{m}	219	71
200 (IV.)	8	16	22	7	151
Add .	35	1	18	226	222
9 (I.)	265	18	36	262	232
	300	19	54	488	454
Oct. (II.)	273			360	360
	27	19	54		

Here we must go back a lunation, for it is clear that the addition for new style will give the November moon.

	35	1	18	226	222
8 (I.)	236	5	52	233	207
New style	13				
Add .	284	7	10	459	429
Oct. (II.)	273			360	360
Subtract	11	7	10	99	69
99 (VI. A)		0	2		
69 (VI. B)		19	10		
Add .	12	2	22		

Answer, Oct. 12, at 2^{h} 22^{m} after noon.

Hutton, 'Dict.' art. *Eclipse* } Oct. 12, at 2 28 after noon.

Error, six minutes.

The student who uses this method will soon learn by practice to avoid being thrown back by a wrong number of lunations, though we have thought it best in the above examples to insert both the wrong guess and its correction. The use of Table VII. will obviate the difficulty in ninety-nine cases out of a hundred. The days of January being in the first column, the succeeding columns show (within one day) when the succeeding full or new moons will happen, according to the day of January, which is that of full or new moon. Thus, if it be full moon on January 19, it is full moon, or very close upon it, on February 17, March 19, April 17, &c., and nine lunations bring us to October 11.

It will happen sometimes that instead of the January moon, the first part of the rule gives the February moon. As in the second example preceding, where the result is that there is mean new moon on the *thirty-fifth* of January, which is the fourth of February. This, if seen, should have been a warning to count lunations from February instead of January.

EXAMPLE 3.—Walther is said to have observed an eclipse of the sun at Nüremberg (11° 5′ east of Greenwich) on the 16th of March, 1485, the middle being at 4^{h} 27^{m} in the afternoon. What was the Nüremberg time of new moon *in March, 1485?*

				A	B
1785 (III.)	28^{d}	5^{h}	5^{m}	221	160
300 (IV.)	13	0	33	10	46
Subtract	15	4	32	211	114
2 (I.)	59	1	28	58	52
Add	74	6	0	269	166
March (II.)	59				
	15	6	0		
269 (VI. A) . . .		8	22		
		12	0		
	16	2	22	at Greenwich.	
11° 5′ is			44		
	16	3	6		

Answer, March 16, at 3^{h} 6^{m} after noon.

EXAMPLE 4.—November 29, 1621, an eclipse of the moon at about three o'clock in the morning is recorded. If the record be true, it must have been full moon: required the full moon of November, 1621.

				A	B
1721 (III.)	1^{d}	5^{h}	15^{m}	194	40
100 (IV.)	4	8	11	3	255
Subtract			Impossible.		

We must therefore add a lunation before beginning.

				A	B	
1 (I.)	29^{d}	12^{h}	44^{m}	29	26	add
Add 1721 (III.)	1	5	15	194	40	360
Subtract 100 (IV.)	4	8	11	3	255	here.
	26	9	48	220	171	
Add 10 (I.)	295	7	20	291	258	
Subtract Nov. (II.)	304					
	17	17	8	511	429	
New style	10			360	360	
151 (VI. A)		2	7	151	69	
69 (VI. B)		19	10			
Add	28	14	25			

Answer, November 29, at 2^{h} 25^{m} in the morning.

Taking a few consecutive instances, we have the following results:—

	By the Tables.			By the Almanac.			Error.
1836, January, Full Moon	3^{d}	12^{h}	49^{m}	3^{d}	13^{h}	5^{m}	16^{m}
New Moon	17	20	35	17	20	28	7
„ February, Full Moon	2	6	45	2	6	50	5
New Moon	16	8	34	16	8	18	16
„ March, Full Moon	2	22	11	2	21	52	19

TABLE I.

Lun.	d.	h.	m.	A	B
1	29	12	44	29	26
2	59	1	28	58	52
3	88	14	12	87	77
4	118	2	56	116	103
5	147	15	40	146	129
6	177	4	24	175	155
7	206	17	8	204	181
8	236	5	52	233	207
9	265	18	36	262	232
10	295	7	21	291	258
11	324	20	5	320	284
12	354	8	49	349	310
13	383	21	33	18	336

TABLE II.

Months.	Days.	
For	*Subt.*	Days to be subtracted.
January	0	
February	31	
March	59	
April	90	
May	120	
June	151	
July	181	
August	212	
September	243	
October	273	
November	304	
December	334	

TABLE III.—The Mean Times of New and Full Moon in January, from A.D. 1700 to A.D. 1800, according to the old style.

Years.		New Moon.					Full Moon.				
		d.	h.	m.	A	B	d.	h.	m.	A	B
L.	1700	8	0	43	202	1	22	19	5	217	194
	1701	26	22	16	221	336	12	3	54	206	143
	1702	16	7	5	210	286	1	12	43	195	93
	1703	5	15	53	199	236	20	10	15	214	69
L.	1704	23	13	26	218	211	8	19	4	203	18
	1705	12	22	15	207	161	27	16	37	222	354
	1706	2	7	3	196	111	17	1	25	211	304
	1707	21	4	36	215	87	6	10	14	200	254
L.	1708	9	13	24	203	36	24	7	46	218	229
	1709	28	10	57	222	12	13	16	35	207	179
	1710	17	19	46	211	322	3	1	24	196	129
	1711	7	4	34	200	272	21	22	56	215	105
L.	1712	25	2	7	219	247	10	7	45	204	55
	1713	14	10	56	208	197	29	5	18	223	30
	1714	3	19	44	197	147	18	14	6	212	340
	1715	22	17	17	216	122	7	22	55	201	290
L.	1716	11	2	5	205	72	25	20	27	220	265
	1717	0	10	54	194	22	15	5	16	209	215
	1718	19	8	27	213	358	4	14	5	198	165
	1719	8	17	15	202	308	23	11	37	217	140
L.	1720	26	14	48	220	283	11	20	26	205	90
	1721	15	23	37	209	233	1	5	15	194	40
	1722	5	8	25	198	183	20	2	47	213	16
	1723	24	5	58	217	158	9	11	36	202	325
L.	1724	12	14	47	206	108	27	9	9	221	301
	1725	1	23	35	195	58	16	17	57	210	251
	1726	20	21	8	214	34	6	2	46	190	201
	1727	10	5	56	203	344	25	0	18	218	177
L.	1728	28	3	29	222	319	13	9	7	207	126
	1729	17	12	18	211	269	2	17	56	196	76
	1730	6	21	6	200	219	21	15	28	215	52
	1731	25	18	38	219	194	11	0	16	204	1
L.	1732	14	3	28	208	144	28	21	49	223	337
	1733	3	12	16	197	94	18	6	38	212	287
	1734	22	9	49	216	69	7	15	27	201	236
	1735	11	18	37	205	19	26	12	59	220	212
L.	1736	0	3	26	194	329	14	21	48	209	162
	1737	*19*	0	59	213	305	4	6	37	198	112
	1738	*8*	*9*	*47*	202	254	23	4	9	217	87
	1739	*27*	*7*	*20*	220	230	12	12	58	205	37

Years.		New		
		d.	h.	m.
L.	1740	15	16	9
	1741	5	0	57
	1742	23	22	30
	1743	13	7	18
L.	1744	1	16	7
	1745	20	13	40
	1746	9	22	28
	1747	28	20	1
L.	1748	17	4	50
	1749	6	13	38
	1750	25	11	11
	1751	14	19	59
L.	1752	3	4	48
	1753	22	2	21
	1754	11	11	9
	1755	0	19	58
L.	1756	18	17	31
	1757	8	2	19
	1758	26	23	52
	1759	16	8	41
L.	1760	4	17	29
	1761	23	15	2
	1762	12	23	50
	1763	2	8	39
L.	1764	20	6	12
	1765	9	15	0
	1766	28	12	33
	1767	17	21	22
L.	1768	6	6	10
	1769	25	3	43
	1770	14	12	31
	1771	3	21	20
L.	1772	21	18	53
	1773	11	3	41
	1774	0	12	30
	1775	19	10	3
L.	1776	7	18	51
	1777	26	16	24
	1778	16	1	12
	1779	5	10	1
L.	1780	23	7	34
	1781	12	16	22
	1782	2	1	11
	1783	20	22	44
L.	1784	9	7	32
	1785	28	5	5
	1786	17	13	54
	1787	6	22	42
L.	1788	24	20	15
	1789	14	5	3
	1790	3	13	52
	1791	22	11	25
L.	1792	10	20	13
	1793	0	5	2
	1794	19	2	35
	1795	8	11	23
L.	1796	26	8	56
	1797	15	17	44
	1798	5	2	33
	1799	24	0	6
L.	*1800*	12	8	54

TABLE IV.

Years.	d.	h.	m.	A	B	Years.	d.	h.	m.	A	B
100	4	8	11	3	255	1600	10	9	26	355	74
200	8	16	22	7	151	1700	14	17	37	359	330
300	13	0	33	10	46	1800	19	1	48	2	225
400	17	8	43	13	301	1900	23	9	58	5	120
500	21	16	54	17	197	2000	27	18	9	9	16
600	26	1	5	20	92	2100	2	13	36	343	245
700	0	20	32	354	322	2200	6	21	47	346	141
800	5	4	43	358	217	2300	11	5	58	350	36
900	9	12	54	1	112	2400	15	14	9	353	291
1000	13	21	5	4	8	2500	19	22	20	356	187
1100	18	5	16	8	263	2600	24	6	31	0	82
1200	22	13	26	11	159	2700	28	14	41	3	337
1300	26	21	37	14	54	2800	3	10	8	337	207
1400	1	17	4	349	284	2900	7	18	19	341	102
1500	6	1	15	352	179	3000	12	2	30	344	358

TABLE V.

Dates.	h.	m.	B	Dates.	h.	m.	B
B.C. 1000	3	51	8	A.D. 700	0	33	1
900	3	35	7	800	0	27	1
800	3	19	7	900	0	21	1
700	3	4	6	1000	0	16	1
600	2	49	6	1100	0	12	0
500	2	35	5	1200	0	8	0
400	2	22	5	1300	0	5	0
300	2	9	4	1400	0	3	0
200	1	57	4	1500	0	1	0
100	1	45	4	1600	0	0	0
0	1	34	3	1700	0	0	0
A.D. 100	1	23	3	1800	0	0	0
200	1	13	2	1900	0	1	0
300	1	4	2	2000	0	3	0
400	0	55	2	2100	0	5	0
500	0	47	2	2200	0	8	0
600	0	40	1				

TABLE VI.

	A		B			A		B			A		B	
	h.	m.	h.	m.		h.	m.	h.	m.		h.	m.	h.	m.
1	4	7	9	59	13	3	16	12	10	25	2	27	14	13
2	4	2	10	10	14	3	12	12	20	26	2	23	14	23
3	3	58	10	21	15	3	7	12	31	27	2	19	14	32
4	3	54	10	32	16	3	3	12	42	28	2	15	14	42
5	3	50	10	43	17	2	59	12	52	29	2	12	14	52
6	3	46	10	54	18	2	55	13	2	30	2	8	15	1
7	3	42	11	5	19	2	51	13	13	31	2	4	15	10
8	3	37	11	16	20	2	47	13	23	32	2	0	15	19
9	3	33	11	27	21	2	43	13	33	33	1	57	15	28
10	3	29	11	38	22	2	39	13	43	34	1	54	15	37
11	3	24	11	49	23	2	35	13	53	35	1	50	15	45
12	3	20	11	59	24	2	31	14	3	36	1	46	15	54

Table VI.—*continued.*

A		B			A		B			A		B	
h.	m.	h.	m.		h.	m.	h.	m.		h.	m.	h.	m.
1	43	16	2	95	0	1	19	30	153	2	15	13	57
1	39	16	11	96	0	1	19	28	154	2	19	13	48
1	36	16	19	97	0	1	19	26	155	2	23	13	39
1	32	16	27	98	0	2	19	24	156	2	27	13	31
1	29	16	35	99	0	2	19	22	157	2	31	13	22
1	26	16	43	100	0	3	19	20	158	2	35	13	13
1	23	16	50	101	0	4	19	18	159	2	39	13	4
1	19	16	58	102	0	5	19	15	160	2	43	12	55
1	16	17	5	103	0	6	19	12	161	2	48	12	46
1	13	17	12	104	0	7	19	9	162	2	52	12	37
1	10	17	19	105	0	8	19	6	163	2	56	12	28
1	7	17	26	106	0	9	19	2	164	3	0	12	18
1	4	17	33	107	0	10	18	59	165	3	5	12	9
1	1	17	39	108	0	11	18	55	166	3	9	12	0
0	58	17	46	109	0	12	18	51	167	3	13	11	51
0	56	17	52	110	0	14	18	47	168	3	18	11	41
0	53	17	58	111	0	15	18	43	169	3	22	11	32
0	51	18	4	112	0	17	18	38	170	3	27	11	23
0	48	18	9	113	0	18	18	34	171	3	31	11	14
0	45	18	15	114	0	20	18	29	172	3	35	11	4
0	43	18	20	115	0	22	18	24	173	3	40	10	55
0	40	18	25	116	0	23	18	19	174	3	44	10	45
0	38	18	30	117	0	25	18	14	175	3	49	10	36
0	36	18	35	118	0	27	18	8	176	3	53	10	26
0	34	18	40	119	0	29	18	3	177	3	58	10	17
0	32	18	44	120	0	31	17	57	178	4	2	10	7
0	30	18	48	121	0	34	17	51	179	4	7	9	58
0	28	18	52	122	0	36	17	45	180	4	11	9	48
0	26	18	56	123	0	38	17	40	181	4	15	9	38
0	24	19	0	124	0	40	17	34	182	4	20	9	29
0	22	19	4	125	0	43	17	28	183	4	24	9	19
0	20	19	7	126	0	45	17	22	184	4	29	9	10
0	19	19	10	127	0	48	17	15	185	4	33	9	0
0	17	19	13	128	0	51	17	9	186	4	38	8	51
0	15	19	16	129	0	53	17	2	187	4	42	8	41
0	14	19	19	130	0	56	16	56	188	4	47	8	32
0	13	19	21	131	0	59	16	49	189	4	51	8	22
0	12	19	23	132	1	2	16	42	190	4	55	8	13
0	11	19	25	133	1	5	16	35	191	5	0	8	4
0	10	19	27	134	1	8	16	28	192	5	4	7	55
0	9	19	29	135	1	11	16	21	193	5	9	7	45
0	8	19	30	136	1	14	16	14	194	5	13	7	36
0	7	19	32	137	1	17	16	6	195	5	17	7	27
0	6	19	33	138	1	20	15	59	196	5	22	7	18
0	5	19	34	139	1	24	15	51	197	5	26	7	8
0	4	19	35	140	1	27	15	44	198	5	30	6	59
0	3	19	35	141	1	30	15	36	199	5	34	6	50
0	2	19	36	142	1	34	15	28	200	5	39	6	41
0	2	19	36	143	1	37	15	20	201	5	43	6	32
0	1	19	36	144	1	41	15	12	202	5	47	6	23
0	1	19	36	145	1	45	15	4	203	5	51	6	14
0	1	19	36	146	1	48	14	56	204	5	55	6	5
0	0	19	35	147	1	52	14	48	205	5	59	5	57
0	0	19	35	148	1	56	14	39	206	6	3	5	48
0	0	19	34	149	1	59	14	31	207	6	7	5	39
0	0	19	33	150	2	3	14	23	208	6	11	5	31
0	0	19	32	151	2	7	14	14	209	6	15	5	22
0	0	19	31	152	2	11	14	5	210	6	19	5	13

TABLE VI.—*continued.*

	A		B			A		B			A		B	
	h.	m.	h.	m.		h.	m.	h.	m.		h.	m.	h.	m.
211	6	23	5	5	261	8	20	0	14	311	7	18	2	3
212	6	26	4	57	262	8	20	0	12	312	7	15	2	10
213	6	30	4	49	263	8	21	0	10	313	7	12	2	17
214	6	34	4	40	264	8	21	0	8	314	7	9	2	24
215	6	37	4	32	265	8	21	0	6	315	7	6	2	31
216	6	41	4	24	266	8	22	0	5	316	7	3	2	38
217	6	45	4	16	267	8	22	0	4	317	7	0	2	46
218	6	48	4	8	268	8	22	0	3	318	6	56	2	53
219	6	52	4	0	269	8	22	0	2	319	6	53	3	1
220	6	55	3	52	270	8	22	0	1	320	6	50	3	9
221	6	58	3	45	271	8	22	0	1	321	6	46	3	17
222	7	2	3	37	272	8	21	0	1	322	6	43	3	25
223	7	5	3	30	273	8	21	0	0	323	6	39	3	34
224	7	8	3	22	274	8	20	0	0	324	6	36	3	42
225	7	11	3	15	275	8	20	0	0	325	6	32	3	51
226	7	14	3	8	276	8	19	0	1	326	6	29	3	59
227	7	17	3	1	277	8	19	0	1	327	6	25	4	8
228	7	20	2	54	278	8	18	0	2	328	6	22	4	17
229	7	23	2	47	279	8	17	0	3	329	6	18	4	26
230	7	26	2	40	280	8	16	0	4	330	6	14	4	35
231	7	29	2	34	281	8	15	0	6	331	6	10	4	44
232	7	31	2	27	282	8	14	0	7	332	6	7	4	54
233	7	34	2	21	283	8	13	0	9	333	6	3	5	2
234	7	37	2	14	284	8	12	0	11	334	5	59	5	13
235	7	39	2	8	285	8	11	0	13	335	5	55	5	23
236	7	41	2	2	286	8	10	0	14	336	5	51	5	33
237	7	44	1	56	287	8	9	0	16	337	5	47	5	43
238	7	46	1	51	288	8	8	0	18	338	5	43	5	53
239	7	48	1	45	289	8	7	0	20	339	5	39	6	3
240	7	50	1	39	290	8	5	0	23	340	5	35	6	13
241	7	53	1	33	291	8	3	0	26	341	5	31	6	23
242	7	55	1	28	292	8	2	0	29	342	5	27	6	34
243	7	57	1	22	293	8	0	0	32	343	5	23	6	44
244	7	59	1	17	294	7	58	0	36	344	5	19	6	54
245	8	0	1	12	295	7	56	0	40	345	5	15	7	5
246	8	2	1	7	296	7	54	0	44	346	5	10	7	16
247	8	4	1	2	297	7	52	0	48	347	5	6	7	26
248	8	6	0	58	298	7	50	0	52	348	5	2	7	37
249	8	7	0	53	299	7	48	0	56	349	4	58	7	48
250	8	9	0	49	300	7	46	1	1	350	4	54	7	58
251	8	10	0	46	301	7	44	1	6	351	4	49	8	9
252	8	11	0	42	302	7	41	1	11	352	4	45	8	20
253	8	12	0	38	303	7	39	1	16	353	4	41	8	31
254	8	13	0	35	304	7	37	1	22	354	4	37	8	42
255	8	14	0	31	305	7	34	1	27	355	4	33	8	53
256	8	15	0	27	306	7	31	1	32	356	4	28	9	4
257	8	16	0	24	307	7	29	1	38	357	4	24	9	15
258	8	17	0	21	308	7	26	1	44	358	4	20	9	26
259	8	18	0	19	309	7	23	1	50	359	4	15	9	37
260	8	19	0	16	310	7	21	1	57	360	4	11	9	48

Table VII.

Jan.	1	2	3	4	5	6	7	8	9	10	11	12
1	Jan. 31	Mar. 1	Mar. 31	Apr. 29	May 29	Jun. 27	Jul. 27	Aug 25	Sept. 24	Oct. 23	Nov. 22	Dec. 21
2	Feb. 1	2	Apr. 1	30	30	28	28	26	25	24	23	22
3	2	3	2	May 1	31	29	29	27	26	25	24	23
4	3	4	3	2	Jun. 1	30	30	28	27	26	25	24
5	4	5	4	3	2	Jul. 1	31	29	28	27	26	25
6	5	6	5	4	3	2	Aug. 1	30	29	28	27	26
7	5	7	5	5	3	3	1	31	29	29	27	27
8	6	8	6	6	4	4	2	Sept. 1	30	30	28	28
9	7	9	7	7	5	5	3	2	Oct. 1	31	29	29
10	8	10	8	8	6	6	4	3	2	Nov. 1	30	30
11	9	11	9	9	7	7	5	4	3	2	Dec. 1	31
12	10	12	10	10	8	8	6	5	4	3	2	
13	11	13	11	11	9	9	7	6	5	4	3	
14	12	14	12	12	10	10	8	7	6	5	4	
15	13	15	13	13	11	11	9	8	7	6	5	
16	14	16	14	14	12	12	10	9	8	7	6	
17	15	17	15	15	13	13	11	10	9	8	7	
18	16	18	16	16	14	14	12	11	10	9	8	
19	17	19	17	17	15	15	13	12	11	10	9	
20	18	20	18	18	16	16	14	13	12	11	10	
21	19	21	19	19	17	17	15	14	13	12	11	
22	20	22	20	20	18	18	16	15	14	13	12	
23	21	23	21	21	19	19	17	16	15	14	13	
24	22	24	22	22	20	20	18	17	16	15	14	
25	23	25	23	23	21	21	19	18	17	16	15	
26	24	26	24	24	22	22	20	19	18	17	16	
27	25	27	25	25	23	23	21	20	19	18	17	
28	26	28	26	26	24	24	22	21	20	19	18	
29	27	29	27	27	25	25	23	22	21	20	19	
30	28	30	28	28	26	26	24	23	22	21	20	

LONDON: WILLIAM CLOWES AND SONS, STAMFORD STREET.